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College of Agricultural, Consumer and Environmental Sciences
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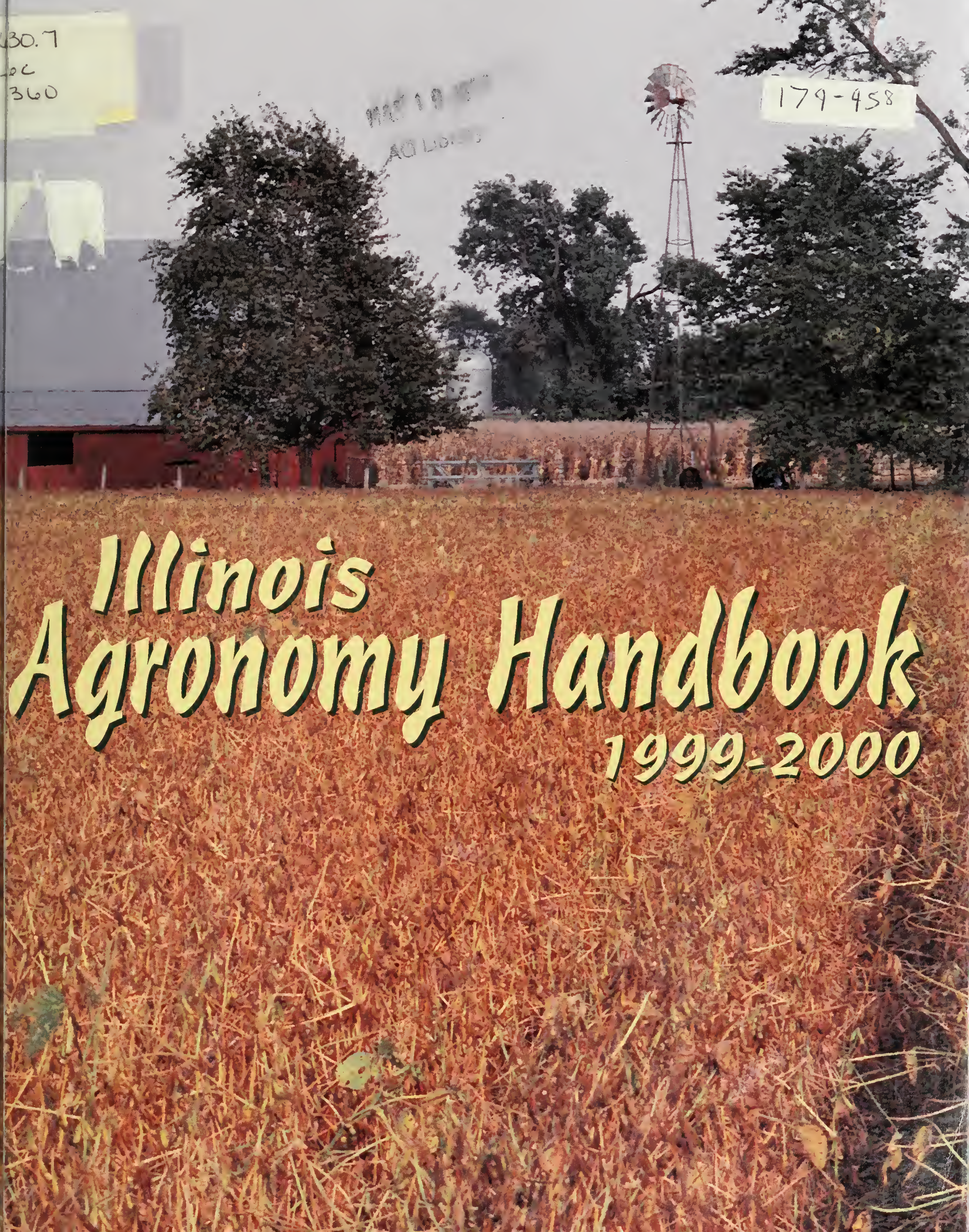
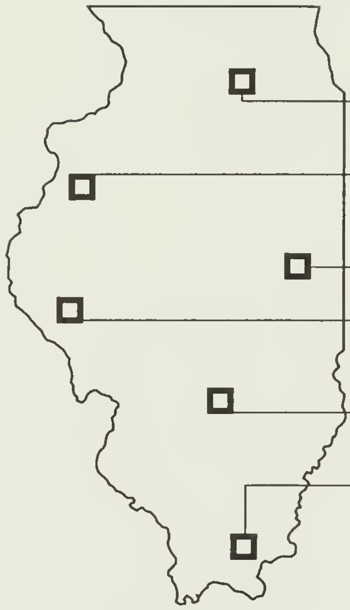


Illinois Agronomy Handbook 1999-2000

Agricultural Research and Demonstration Centers



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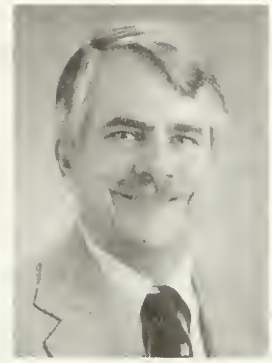
Michael E. Gray


Aaron G. Hager


Robert G. Hoeft


Steven E. Hollinger


H. Walker Kirby


Marshal D. McGlamery


James A. Morrison


Emerson D. Nafziger


Theodore R. Peck


Gary E. Pepper


David R. Pike


John C. Siemens


F. William Simmons


Kevin L. Steffey

Contents

Chapter 1. Agricultural Climatology

Year-to-year and day-to-day variation of weather complicates the scheduling of agricultural practices. However, the use of continuous weather observations, weather forecasts, and climate data may assist in scheduling crop management practices for optimum benefit.

Accurate recording of weather conditions each year helps to indicate the current status of crop and pest development. The future development of crops and pests can be estimated using observed weather data related to current time, combined with past climate data and weather forecasts. Forecasts are available up to 90 days into the future, with forecast skill decreasing as the length of the forecast period increases (with a 90-day forecast the least reliable). Short-term forecasts (defined as those between 12 hours and 5 days) include information on anticipated temperature, rainfall, relative humidity, and winds. Longer-term forecasts (6- to 10-day, 30-day, and 90-day) are limited to indications of future temperature and precipitation.

Weather Variables

Variables including air and soil temperatures, precipitation, humidity, solar radiation, soil moisture, and wind are measured frequently throughout the day, week, and month. Information gathered from these measurements is used to calculate other variables that are important to agriculture, such as evapotranspiration, growing degree days, heat and cold stress days, and days suitable for field work.

Although often viewed as the same products, weather and climate data are different. Weather data describe the state of the atmosphere at a specified time, whereas climate data summarize weather conditions over many years. Climate data reflect the mean and variation of weather conditions during given time periods. Climate data can be used to estimate the timing of biological events, such as crop growth and crop, insect, and disease stages. These estimates can then be used to plan the timing of production practices.

The number of days available for completing spring and fall field work is determined by the weather and plays a major role in limiting the number of acres a producer can farm. A region's climate thus helps determine the size and number of tractors, combines, and tillage implements needed to complete field work in a timely manner.

This chapter discusses the importance of understanding the climate of Illinois as it relates to factors that influence the management of agricultural crops.

Climate Variables

Temperature

The growing season is generally defined as the period between the last spring frost and the first fall frost. Most annual crops are planted after the major risk of frost or freeze has passed. However, late frosts—particularly very late frosts—can damage both annual and perennial crops during the spring. Mean dates of last spring frosts occur as early as April 9 in southern Illinois and as late as May 4 in northern Illinois (Figure 1.01). In 1 out of every 10 years, the last spring frost can occur as early as March 27 and as late as April 24 in southern Illinois, and as early as April 21 and as late as May 14 in northern Illinois.

The average dates of first fall frosts range from October 6 in northern Illinois to October 21 in southern Illinois. In 1 out of 10 years, the first fall frost occurs by September 26 in northern Illinois and October 6 in southern Illinois (Figure 1.02). In 9 out of 10 years, the first frost occurs before or on October 21 in northern Illinois and November 5 in southern Illinois.

Mean minimum temperatures (°F) for Illinois range from the mid-teens to mid-twenties in winter to the low to mid-sixties in the summer (Figure 1.03). Mean minimum temperatures during the spring and autumn range from the upper thirties to mid-forties. Mean maximum temperatures range from the low thirties to mid-forties during the winter. Summer

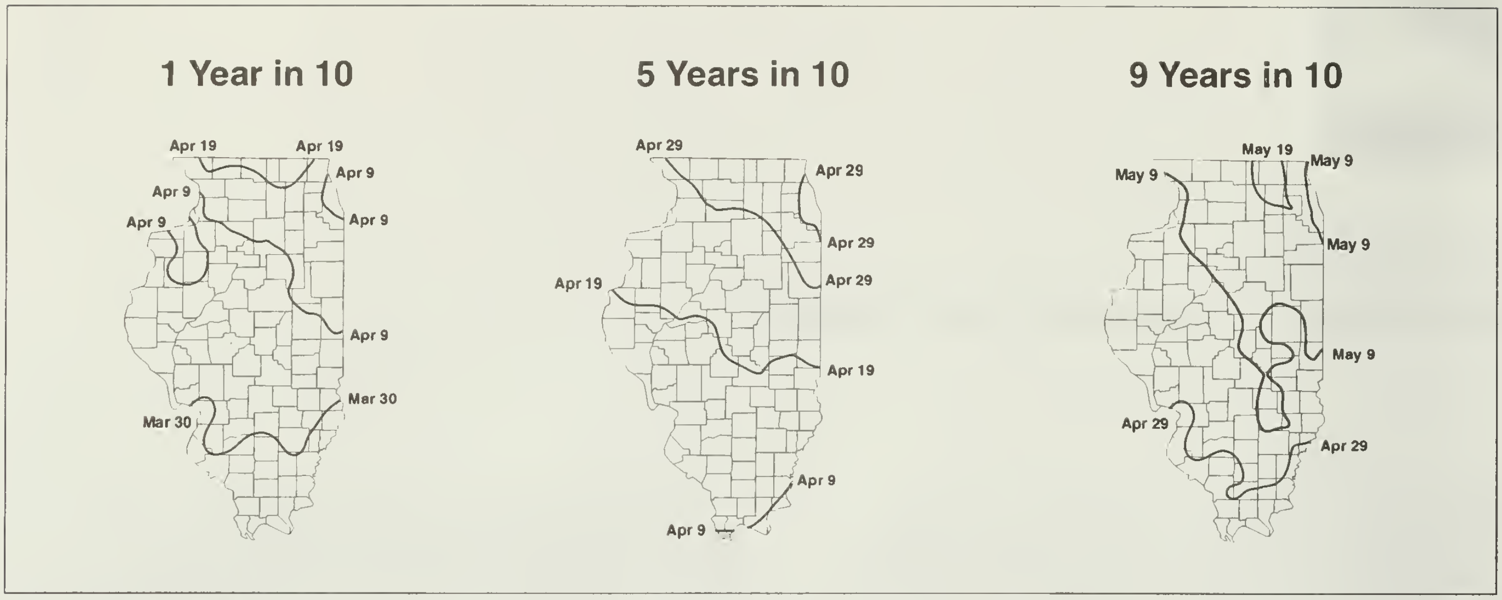


Figure 1.01. Probable dates of last spring frost (32°F minimum temperature).

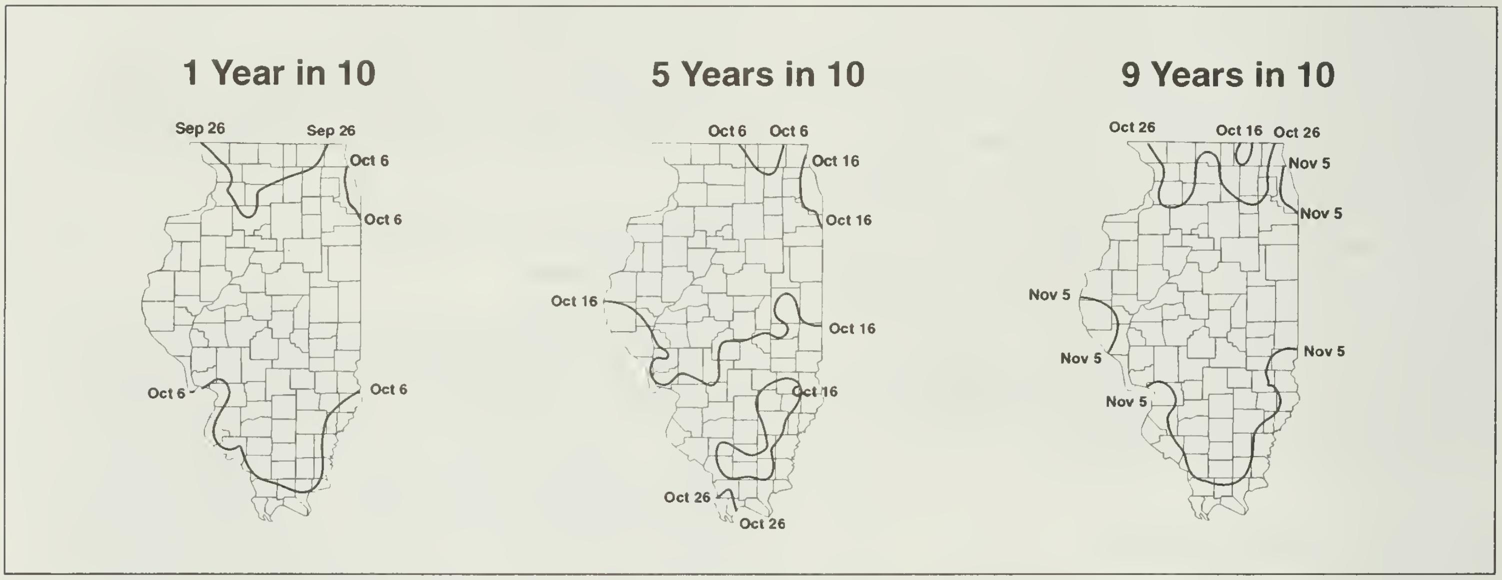


Figure 1.02. Probable dates of first fall frost (32°F minimum temperature).

mean maximum temperatures range from the low eighties in the northern regions of Illinois to the high eighties in the southern regions. Spring and autumn mean maximum temperatures range from the high fifties to low sixties in the north and in the mid- to high sixties in the south. In the north, mean maximum temperatures tend to be cooler in the spring than in the autumn.

Soil temperature. Soil temperatures in the autumn determine when ammonium nitrogen fertilizer may be applied without excessive nitrification occurring during the autumn and winter. At soil temperatures below 50°F the rate of nitrification is reduced, but the process does not stop until temperatures are below 32°F. Soil temperatures throughout the state are below 50°F by mid-November 9 years out of 10 (Figure 1.04). Maps showing the dates when soil temperatures fall below 60°F are included as a guide for estimating when anhydrous ammonia application with a nitrification inhibitor can begin. As a guideline, 50°F soil temperatures occur 25 to 30 days after 60°F soil temperatures.

Precipitation

The type, timing, and amount of precipitation received during the year play a critical role in crop productivity. Mean annual rainfall ranges from 36 inches in the north to 45 inches in the south (Figure 1.05). Annual rainfall of less than 28 inches in the north and less than 34 inches in the south can be

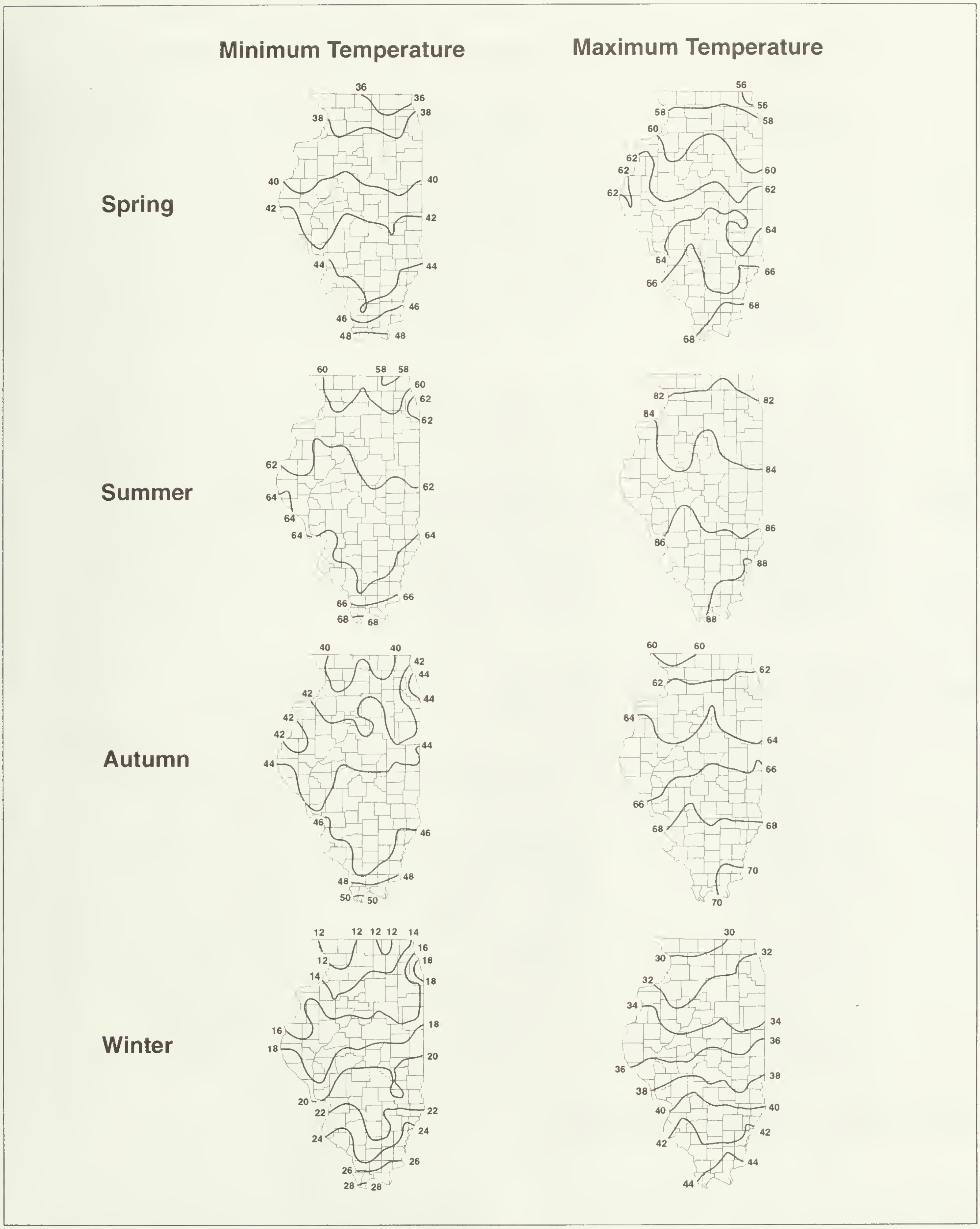


Figure 1.03. Mean maximum and minimum temperatures (°F) for spring, summer, autumn, and winter.

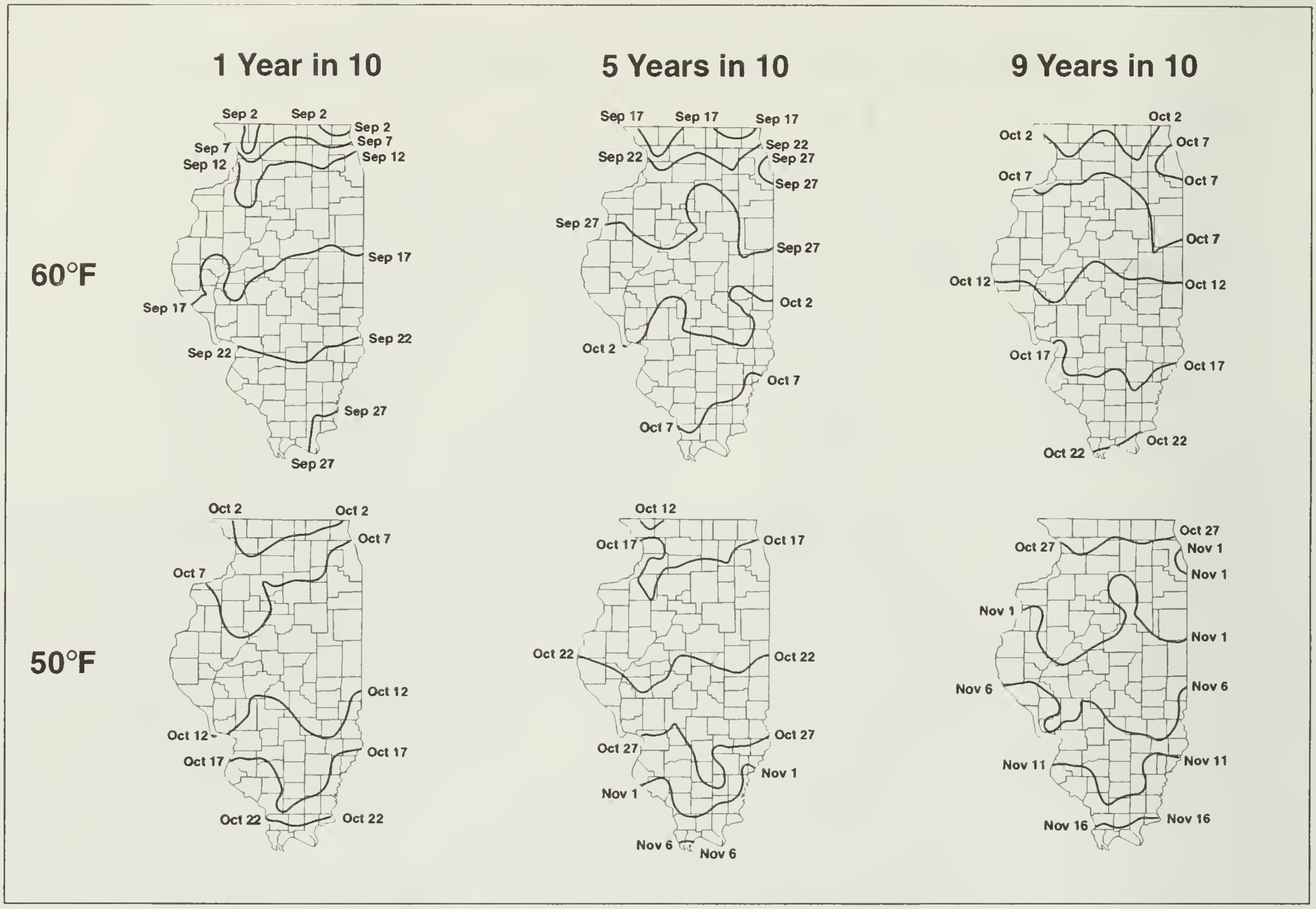


Figure 1.04. Probable first dates in the fall when 4-inch soil temperatures drop below 60°F and 50°F.

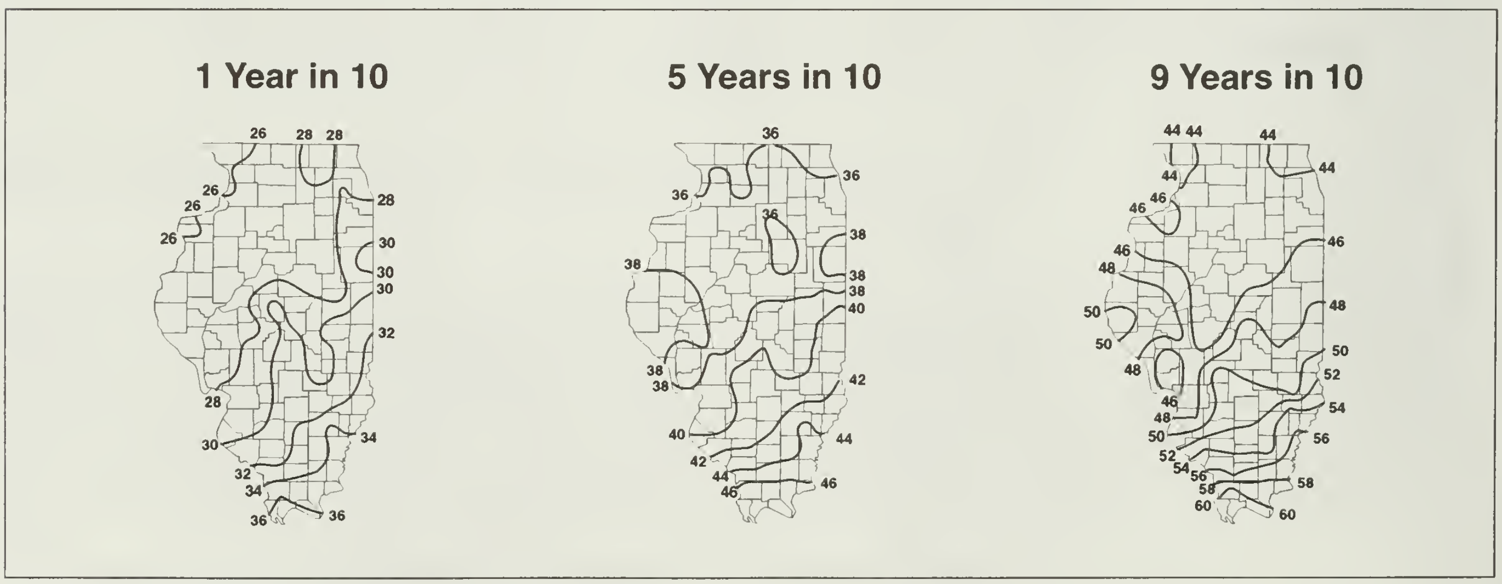


Figure 1.05. Probable annual rainfall amounts (inches).

expected 1 year out of 10. Annual rainfall can be expected to be greater than 46 inches in the north and greater than 52 inches in the south 1 year out of 10.

Winter is the driest season, with approximately 5 inches of precipitation in the north and 10 inches in the south (Figure 1.06). Spring is the wettest season

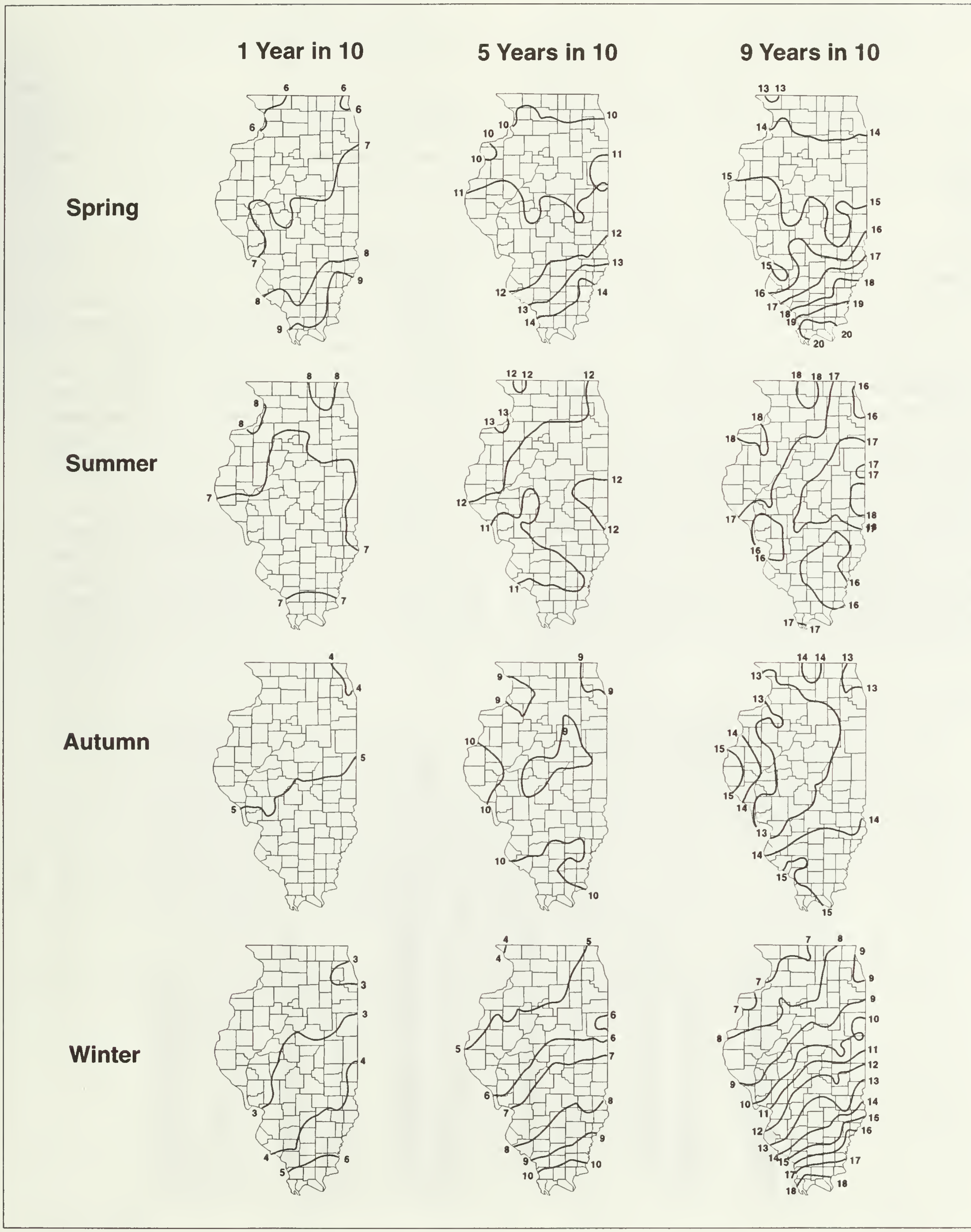


Figure 1.06. Probable seasonal rainfall (inches).

Table 1.01. Average Growing-Season Days with Rain and Average Amounts Per Storm

Month	Days with rain (> 0.10 in.)	Average rain per storm (in.)		
		North	Central	South
April	7	0.53	0.54	0.64
May	7	0.54	0.59	0.70
June	6	0.68	0.65	0.65
July	6	0.65	0.68	0.72
August	5	0.80	0.68	0.64
September	5	0.76	0.72	0.64
October	5	0.52	0.56	0.60

in the south, with more than 13 inches of rain, whereas summer is the wettest season in the north, with 12 inches of rain.

Rain greater than 0.10 inch often delays field work, especially in the spring and early summer, when the soils are the wettest. On average, there are 7 days each month with rainfall greater than 0.10 inch during April and May (Table 1.01), 6 days each in June and July, and 5 days each in August, September, and October. The average rain amount in each storm is larger during the summer than during the spring (Table 1.01). Generally, the average number of days with 0.10 inch of rain in dry and wet years does not change more than 1 day from normal years; the major difference is in the amount of rain received in each storm.

Potential Evapotranspiration

Evapotranspiration is the removal of water from soil by a combination of evaporation from the soil surface and transpiration (loss of water vapor) from plant leaves. Surface evaporation is limited to the upper 2 to 4 inches of soil, while transpiration results in removal of water from the soil to a depth equal to the deepest roots.

"Potential" evapotranspiration is the amount of water that would evaporate from the soil surface and from plants when the soil is at field capacity. Field capacity defines the amount of water soil holds after it has been saturated and then drained, until drainage virtually ceases. Soil drier than field capacity will experience actual evapotranspiration less than the potential evapotranspiration, as will plant canopies that do not totally cover the soil.

Potential evapotranspiration is greatest in dry years with low humidity and predominantly clear skies and least in wet years with high humidity and cloudier-than-normal skies. Total potential evapotranspiration from April though September ranges from about 33 inches in dry years to about 27 inches in wet years. Actual evapotranspiration during wet

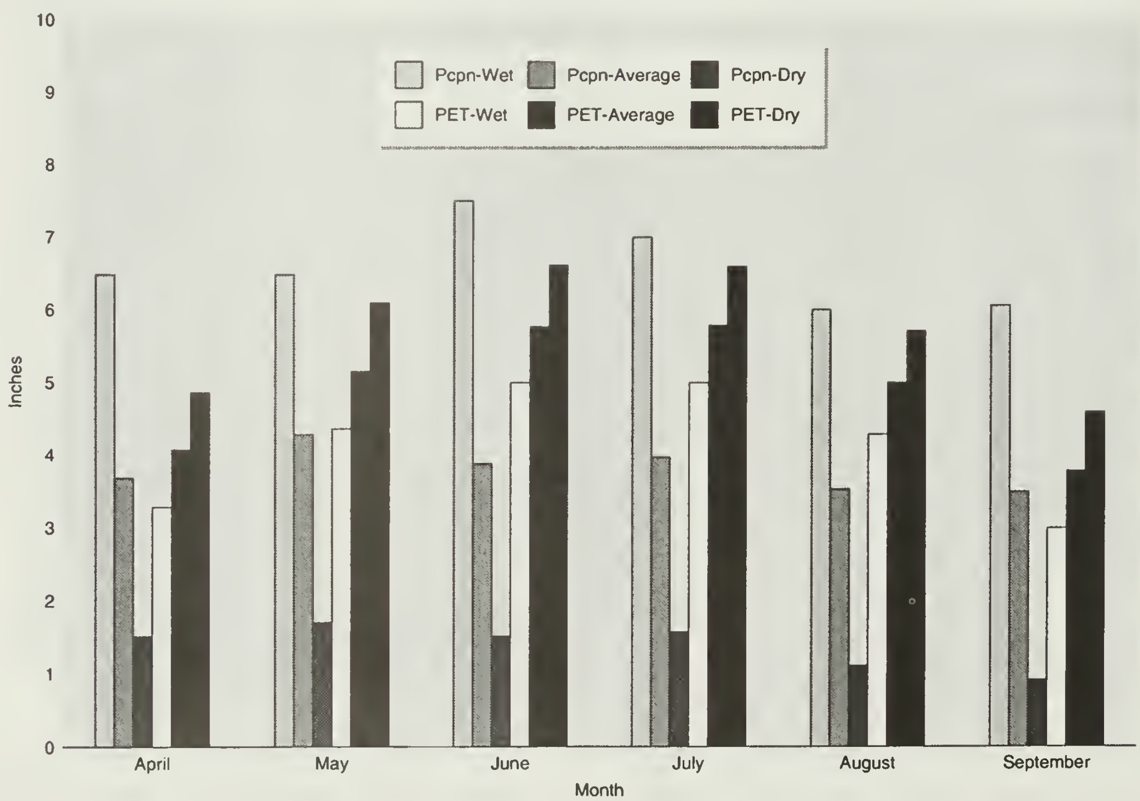


Figure 1.07. Total monthly precipitation (Pcpn) and potential evapotranspiration (PET) during wet, average, and dry years.

years will equal the potential maximum but will be less than the potential maximum in dry years. During the growing season, the normal total monthly evapotranspiration is least in September and greatest in June and July (Figure 1.07). Drought conditions occur when the potential evapotranspiration exceeds rainfall by more than the normal difference for several months in a row.

Soil Moisture

The amount of water held in soil is determined by soil texture, soil drainage, precipitation, and evapotranspiration. During the summer months, evapotranspiration generally exceeds the rainwater absorbed by the soil, and the soil profile dries out. From October through April, evapotranspiration is less than precipitation, and the soil profile is recharged. In Illinois, soils generally become saturated at some time in the spring.

Wet spring soils play an important role in determining how many days are suitable for spring field work. When soil moisture is normal or wetter than normal, even small rains will result in field work delays on all but the sandiest soils in Illinois. Excessive soil moisture in late spring and early summer may result in loss of nitrogen through denitrification and leaching and may lead to the development of seed, root, and crown diseases. Conversely, dry soil during planting may result in poor stand establishment and may cause plant stress when dryness occurs during the periods of flowering and seed set.

The typical arable soil in Illinois is a silt loam or silty clay loam and will, on average, hold approximately 7.5 inches of plant-available water in the top 40 inches of soil. Plant-available water is defined as the amount of water in the soil between field capacity and wilting point. In the uppermost 40 inches of Illinois soils, the average amount of water held at field capacity is approximately 14 inches. The wilting point is defined as the amount of water still in the soil when plants are unable to recover at night from wilting during the day. Illinois soils hold about 6.5 inches of water in the upper 40 inches of soil at the wilting point. Water in the top 40 inches of soil at saturation is approximately 17.5 inches. Individual soils will vary significantly from the average. Coarse-textured soils, such as sands, will hold less water at the wilting point and field capacity than fine-textured soils or soils with high clay content.

During the spring planting season, the amount of water in the top 6 inches of soil controls field work activities. When the top 6 inches of soil is wet, planting is delayed, and nitrogen can be lost to either denitrification or leaching. Traffic on or tillage of fields when soil is near field capacity (80 percent of saturation) causes maximum compaction. During average springs, soil moisture conditions in April are wet enough that rains greater than 0.3 inch will bring the soil water to field capacity (Table 1.02). In the wettest years, rains greater than 0.3 inch will result in significant periods of near-saturated soils in the upper 6 inches. The rainfall amounts shown in Table 1.02 are the minimum amounts of rain needed to trigger denitrification and provide optimum compaction conditions. When the subsurface soil levels are dry, more rain than the amounts shown is needed to have this effect. Only in the driest years will soils seldom reach field capacity.

Whenever plant-available water in the to 40 inches of soil is less than 3.8 inches in June, July, or August, plants will show significant moisture stress during the day. Soil moisture is generally below this limit only during the driest months of July and August (Table 1.03). Even in these months, soils should experience some periods above this stress threshold, especially following rains. In the wettest years, plant-available water exceeds plant needs, and periods of saturation may occur during the summer months.

Table 1.02. Water Content in the Top 6-Inch Soil Layer of a Typical Illinois Silt Loam or Silty Clay Loam During April, May, and June, and the Minimum Rain Needed to Bring Soil Moisture to Field Capacity

	Dry		Average		Wet	
Month	Water content (in.)	Rain needed for field capacity (in.)	Water content (in.)	Rain needed for field capacity (in.)	Water content (in.)	Rain needed for field capacity (in.)
April	1.5	0.72	1.9	0.32	2.36	0.00
May	1.18	1.11	1.57	0.72	2.17	0.12
June	0.94	1.35	1.50	0.79	1.97	0.32

Table 1.03. Plant-Available Water in the Top 40-Inch Soil Layer of a Typical Illinois Silt Loam or Silty Clay Loam During June, July, and August

	Plant-available water (in.)		
Month	Dry	Average	Wet
June	4.37	5.16	7.52
July	2.79	5.16	9.04
August	2.01	4.37	6.74

Effects of El Niño and La Niña on Illinois Crops and Weather

Recent extreme weather events in the United States and around the world have been blamed on extremes of sea surface temperatures in the equatorial Pacific Ocean. When sea surface temperatures in the equatorial Pacific are above normal, an El Niño event is occurring. Conversely, when the sea surface temperatures are below normal, a La Niña event is occurring. During years when equatorial Pacific sea surface temperatures are cooling in the spring and summer, corn and soybean yields are below the general yield trends in Illinois. When sea surface temperatures are increasing or not changing, corn and soybean yields are above the yield trends or near normal (Figure 1.08). Yield deviations tend to be above the trend when spring rainfall is below normal and summer rainfall is above normal.

Crop, Insect, and Disease Environmental Thresholds

Crop Environmental Thresholds

Crops are generally grown in regions where temperature and rainfall conditions favor their growth. Where temperature is favorable but natural rainfall is insufficient, crops are irrigated if sufficient water is available. Temperature is a major factor in determining where a specific crop is grown if rainfall or irrigation

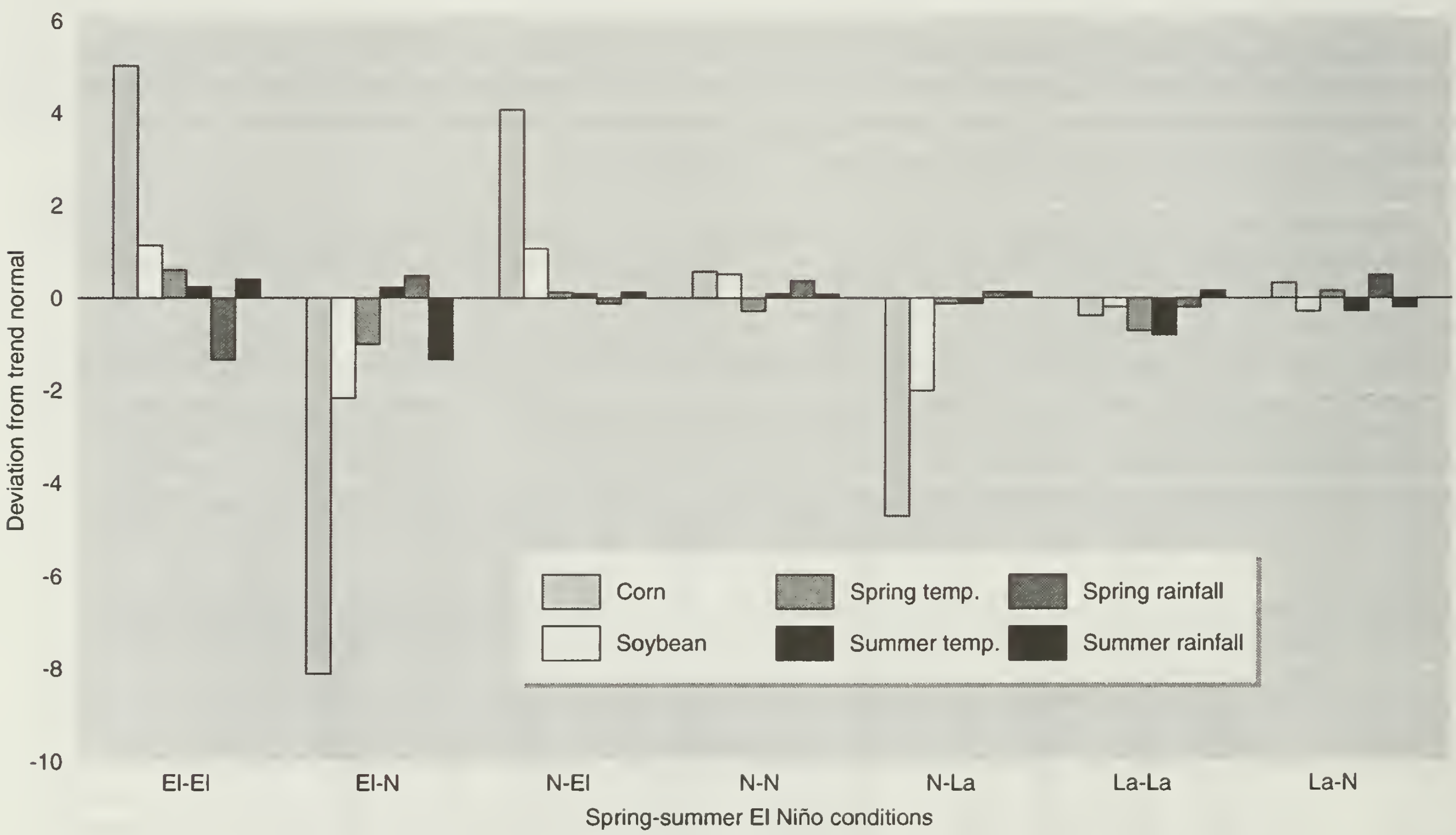


Figure 1.08. Corn and soybean yield response to El Niño, normal, and La Niña conditions. El-El = El Niño spring followed by an El Niño summer; El-N = El Niño spring followed by a normal summer; N-El = Normal spring followed by an El Niño summer; N-N = Normal spring and summer; N-La = Normal spring followed by La Niña summer; La-La = La Niña spring and summer; La-N = La Niña spring followed by a normal summer. A normal summer is one in which the equatorial Pacific sea surface temperatures are near normal. Corn and soybean yield deviations are in bu/ac, temperature deviations are °F, and rainfall deviations are in inches.

water is sufficient. Minimum, optimum, and maximum temperatures—called the "cardinal" temperatures—for growth of the major crops in Illinois are presented in Table 1.04. The corresponding temperatures for photosynthesis are in most cases lower than those for growth. A combination of moisture and temperature stress may result in some type of crop damage. For example, temperatures above 95°F during pollination of corn will result in a reduction of pollen viability and, therefore, a possible reduction in the number of kernels set. Moisture stress during this same period may result in delayed silk emergence and a further reduction in the number of kernels set.

There is little a producer can do to control temperatures across large areas. However, knowledge of how crops respond to temperature can be used to estimate possible yield losses due to temperature stresses. These estimates can be used in planning marketing strategies or pest control procedures.

Growing-degree-day accumulation. Because temperature is a major determinant of the rate of crop development, growing degree days (GDD) have been used for many years to track the development rate of crops and to estimate the time of harvest. (See Chapter 2 for a complete description of growing degree days.) GDD, also called growing degree units (GDU), are calculated by subtracting the lower temperature threshold for crop development (base temperature) from the daily mean temperature, then summing over days. Below the base temperature, or above the maximum temperature, the rate of development is negligible. For example, the base temperature for corn is 50°F. If the temperature is below 50°F, corn development is very slow. The development rates of corn and soybeans are also slowed when the maximum temperature exceeds 86°F.

Modern corn hybrids are rated by the number of GDU after planting necessary to reach maturity. GDU accumulations can be used to help select alternate corn hybrids in years when corn planting is delayed. In years when corn can be planted in late April, there is a greater than 95 percent chance (Figure 1.09) that more GDU are accumulated before the normal first frost date than are needed for maturing a 2,800-GDU corn hybrid in all of the state except the northern third. If planting is delayed until late May, a 2,800-GDU corn hybrid has only a 5 to 10 percent chance of maturing before frost in northern Illinois, a 50 percent chance in central Illinois, and a 95 percent chance in extreme southern Illinois. A 2,400-GDU corn hybrid planted in late May has a 95 percent chance of maturing in the southern half of the state, but only a 50 percent chance in the extreme northern part of Illinois.

Temperature stress. Crops begin to experience stress whenever the maximum or minimum temperature falls outside the range of optimum temperatures (Table 1.04). Heat stress days represent the frequency of daily maximum temperatures exceeding an optimum growing temperature. Cold stress days account for the frequency of daily minimum temperatures below some base temperature.

Most crops in Illinois will experience some degree of heat stress when maximum temperatures exceed 90°F. As maximum temperatures approach 100°F, crops experience significant heat stress, and yields are affected, especially if there is a moisture stress and the extreme temperatures occur for an extended period. Heat stress degree days (sum of the degrees by which the daily maximum temperature exceeds 90°F) provide a measure of the degree of high-temperature stress experienced by summer crops. Heat stress can begin to occur as early as May 17, and the chance of heat stress days continues until September 20 in the north and October 4 in the south (Figure 1.10). Chances of having heat stress days are highest during the week of July 12 to 18.

Minimum temperatures below 50°F cause summer crops to experience cold stress. For soybeans, minimum temperatures below 50°F reduce the rate of photosynthesis the following day. Maximum photosynthesis will not resume until a daily minimum temperature over 63°F occurs. Estimates of the effect of temperature below 50°F on summer crops are provided by the cold stress days. A cold stress degree day occurs when the minimum temperature is less than 50°F but greater than 32°F. Cold stress days can occur as late as June 21 in southern Illinois and as late as July 5 in the north (Figure 1.10). Cold stress days begin to occur again by August 2 in the north and August 30 in the south.

Insect Environmental Thresholds

The development rates of insects and their ability to survive are closely connected to temperature. Development generally occurs only after the temperature is greater than the threshold temperature for a specific insect. An insect heat unit (IHU) is the difference between the mean air temperature and a threshold (base) temperature. IHUs are based on the same concept as GDUs but use different base temperatures. Many insect growth stages have been correlated to IHUs. Therefore, IHUs can be used to estimate the start of field scouting of insects that overwinter in Illinois and begin development shortly after January 1. Survival temperatures, base development temperatures, and IHU accumulations for several important agronomic insects follow.

Table 1.04. Environmental-Variable Thresholds of Different Growth Stages of Important Illinois Agronomic Crops

Crop	Growth stage	Temperature, soil or air (°F)[a]	Minimum soil moisture bars	Water-use efficiency (lb H_2O/lb-dm[b])	Solar radiation for maximum growth (% full sun)
Alfalfa	Planting to emergence	Minimum 34 Optimum 86 Maximum 100	–12 to –15		
	Dormancy	Minimum –4			
	Growing season	Minimum 32–50 Optimum 50–86 Maximum 86–104		993	60
Corn	Planting to emergence	Minimum 46–50 Optimum 90–95 Maximum 104–110	–10 to –12		
	Growing season	Minimum 50–59 Optimum 86–90 Maximum 104–122		388	90
Small grains	Planting to emergence	Minimum 37–41 Optimum 59–81 Maximum 86–104	–15 to –20		
	Growing season	Minimum 32–50 Optimum 50–86 Maximum 86–104		613	60
Sorghum	Planting to emergence	Minimum 46–50 Optimum 90–95 Maximum 104–110	–8 to –15		
	Growing season	Minimum 50–59 Optimum 86–104 Maximum 104–122		402	90
Soybean	Planting to emergence	Minimum 48 Optimum 80–90 Maximum 108	–7		
	Growing season	Minimum 50–59 Optimum 80–90 Maximum 104–122		704	60
Grass pasture	Dormancy				
	Growing season	Minimum 32–50 Optimum 50–86 Maximum 86–104			40

[a]Soil temperatures from planting to emergence, air temperatures during growing season.
[b]Water-use efficiency, pound of water used per pound of dry matter produced.

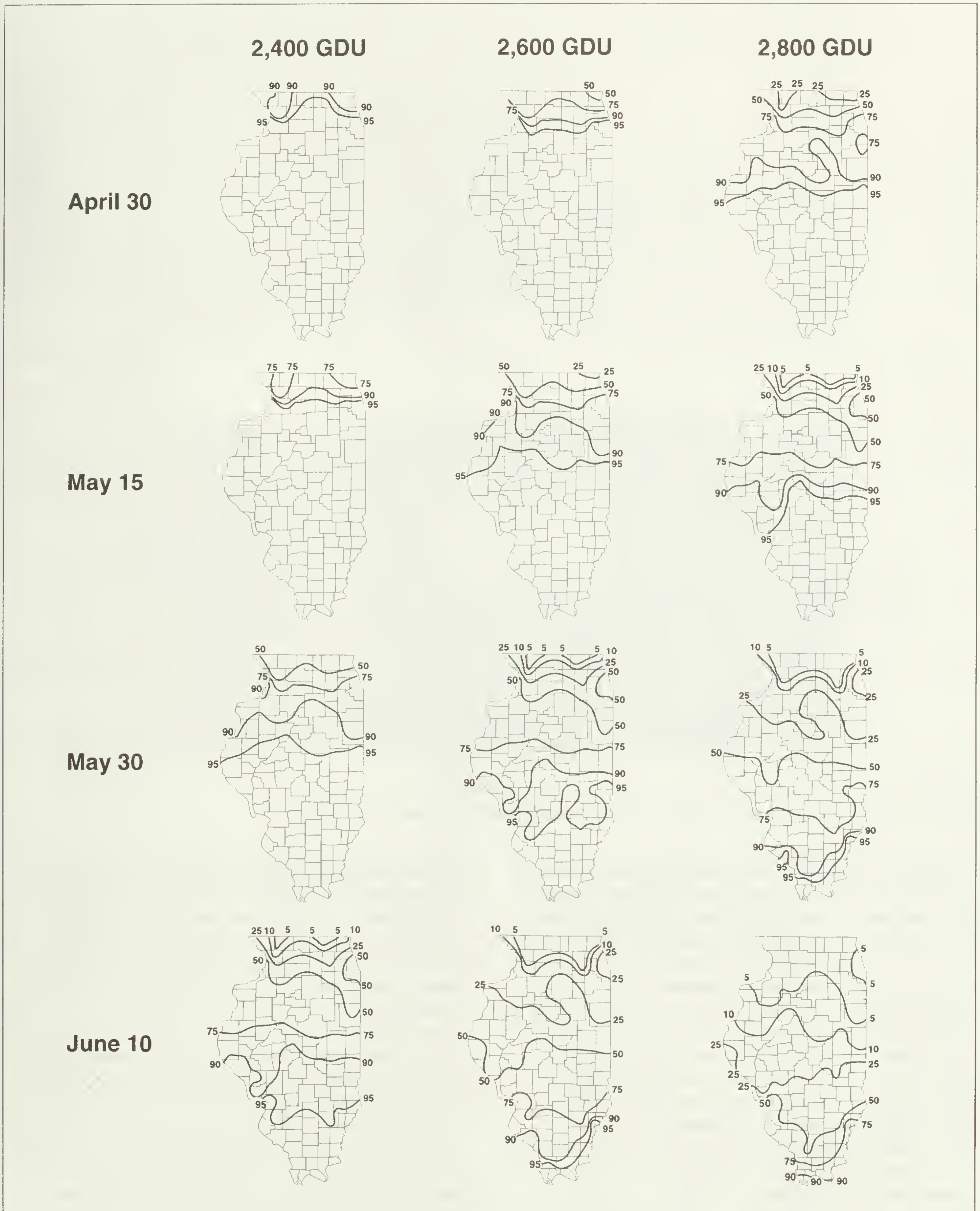


Figure 1.09. Probability of accumulating enough growing degree units (GDU) to mature corn hybrids with different maturity ratings.

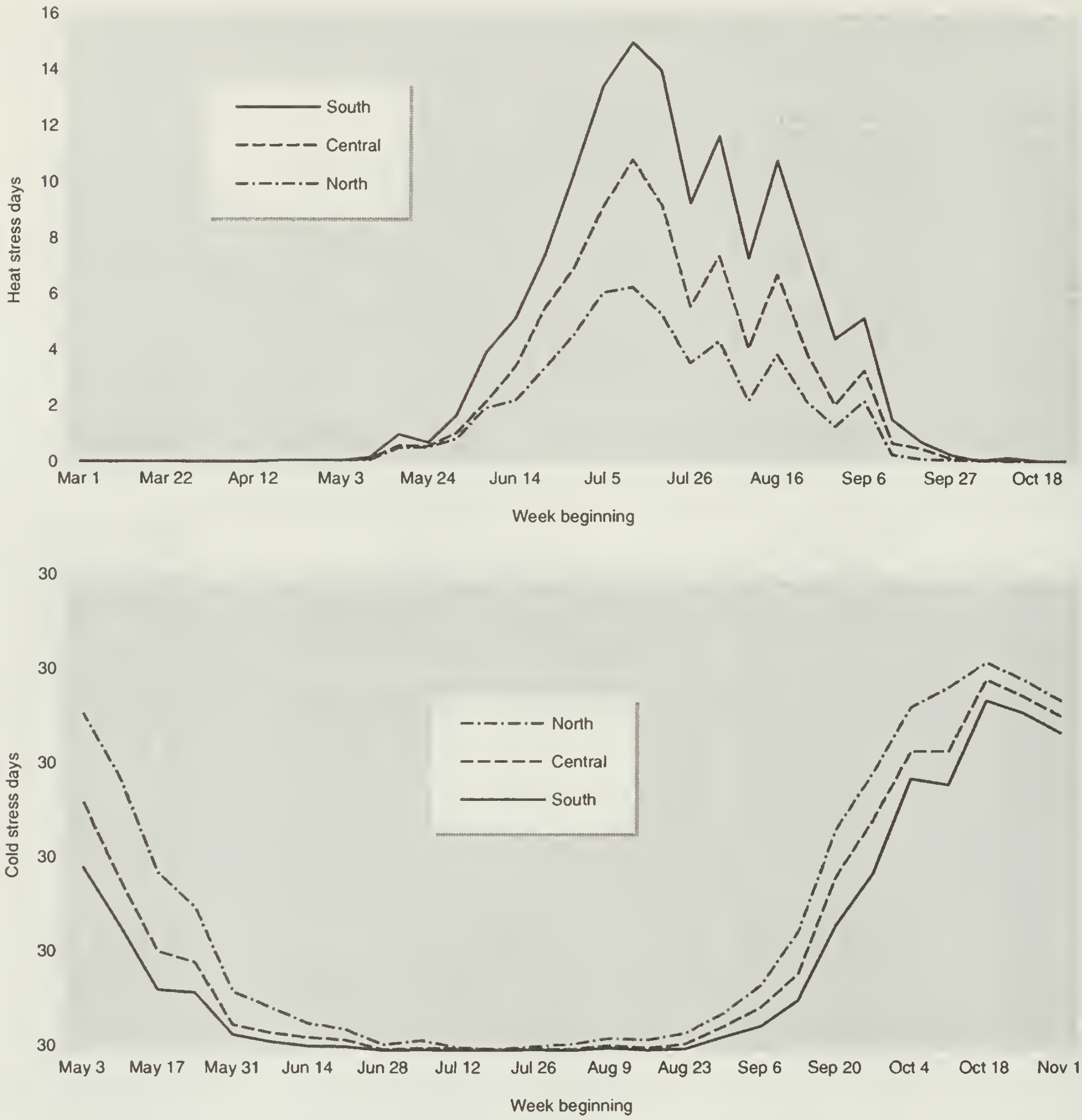


Figure 1.10. Mean heat stress and cold stress days experienced by summer crops in Illinois.

Alfalfa weevil. The alfalfa weevil (*Hypera postica*) begins growth and development at 48°F. Eggs begin to hatch when approximately 200 base 48 IHUs have accumulated from January 1 (Table 1.05). Normally, temperatures cold enough to kill the early weevil larvae (Table 1.06) do not exist in Illinois after the accumulation of 200 to 300 base 48 IHUs. Larval survival rate is high at 54°F.

Nine years in 10, the alfalfa weevil egg hatch will begin by March 31 (Figure 1.11) in southern Illinois, and as early as March 1 for 1 year in 10. In northern Illinois, alfalfa weevil egg hatch normally begins by April 20, but it will start as early as April 10 for 1 year in 10 and by April 30 for 9 years in 10.

Cereal leaf beetle. The cereal leaf beetle (*Oulema melanopus*) overwinters in diapause, which is normally completed by mid-December. Therefore, IHU accumulations begin on January 1. Table 1.06 shows the minimum, maximum, and optimum temperatures at which eggs will hatch, the survival temperature thresholds for different stages of the cereal leaf beetle. Table 1.05 shows the base 48°F growing-degree-day accumulations necessary to reach certain growth stages.

Egg-laying by the cereal leaf beetle begins 1 year in 10 as early as March 31 in southern Illinois and April 20 in northern Illinois (Figure 1.11). Nine years in 10, egg-laying has started by April 20 in the south and by May 10 in the north.

Stalk borer. The stalk borer (*Papaipema nebris*) overwinters as an egg in Illinois, and 50 percent egg hatch should be completed when approximately 278 base 48°F growing degree days have accumulated after January 1. First-generation adults emerge when

Table 1.05. Insect Heat Units (IHU) Required to Reach Various Stages for Important Agronomic Insects in Illinois

Insect	Base temperature (°F)	First flight	Egg	First instar	Second instar	Third instar	Fourth instar	Pupae	Adult
Alfalfa weevil	48		200	270	340	407	497	587	810
Cereal leaf beetle	48		450	607	668	722	785	853	1,274
Black cutworm	50		90	146	200	280	330	610	960
Corn earworm	54		77					360	756
European corn borer	50	423	736	844	969	1,139	1,287	1,520	1,748

Table 1.06. Minimum, Maximum, and Optimum Temperatures (°F) for Insects That Attack Agronomic Crops in Illinois

Insect	Temperature	Egg	First instar	Second instar	Third instar	Fourth instar	Fifth instar	Pupae	Adult
Alfalfa weevil	Minimum	–11	–2	3	14	17		25	
	Optimum	90	90	90	90	86		86	
	Maximum								95
Cereal leaf beetle	Minimum	43	46					46	41
	Optimum	54–90						57–86	
	Maximum	93	93					90	
Black cutworm	Minimum	–4	41	41				23	23
European corn borer	Minimum				18	13	–8		
	Maximum	97	90						

about 3,670 base 41.5°F IHUs have been accumulated.

Egg-hatching of the stalk borer begins in northern Illinois approximately the same time as egg-laying by the cereal leaf beetle. However, the stalk borer egg hatch is 1 to 2 days behind the start of alfalfa weevil egg-hatching (Figure 1.11).

Bean leaf beetle. The development of the bean leaf beetle (*Cerotoma trifurcata*) can be estimated by accumulating IHUs above a base temperature of 45.5°F starting January 1. Bean leaf beetles overwinter as adults and begin emerging from winter habitats after 300 IHUs have accumulated. Bean leaf beetles can be found throughout Illinois. Excessively wet and dry soils result in reduced egg hatching.

Black cutworm. Black cutworm moths (*Agrotis ipislon*) migrate into Illinois in the spring and lay eggs on winter annual weeds in corn fields. Eggs are generally laid before corn planting. Survival temperatures for black cutworm eggs, larvae, and adults are shown in Table 1.06. The development of black cutworm in Illinois can be estimated using a base 50°F IHU, with accumulation beginning after the first intense black cutworm flight in the spring (Table 1.05). An intense flight is defined as 9 or more moths captured per trap over 1 or 2 days. Plant-cutting begins when 300 base 50°F IHUs have accumulated after an intense flight. The projected dates for beginning black cutworm cutting are published in the *Pest Management & Crop Development Bulletin.*

Corn earworm. The corn earworm (*Helicoverpa zea*) is also a migrant into Illinois. Therefore, growing-degree-day accumulations must begin only after arrival of adult moths. The base temperature for IHU accumulation is 54°F, and egg hatch generally occurs after 77 base 54°F IHUs have accumulated (Table 1.05) after egg-laying.

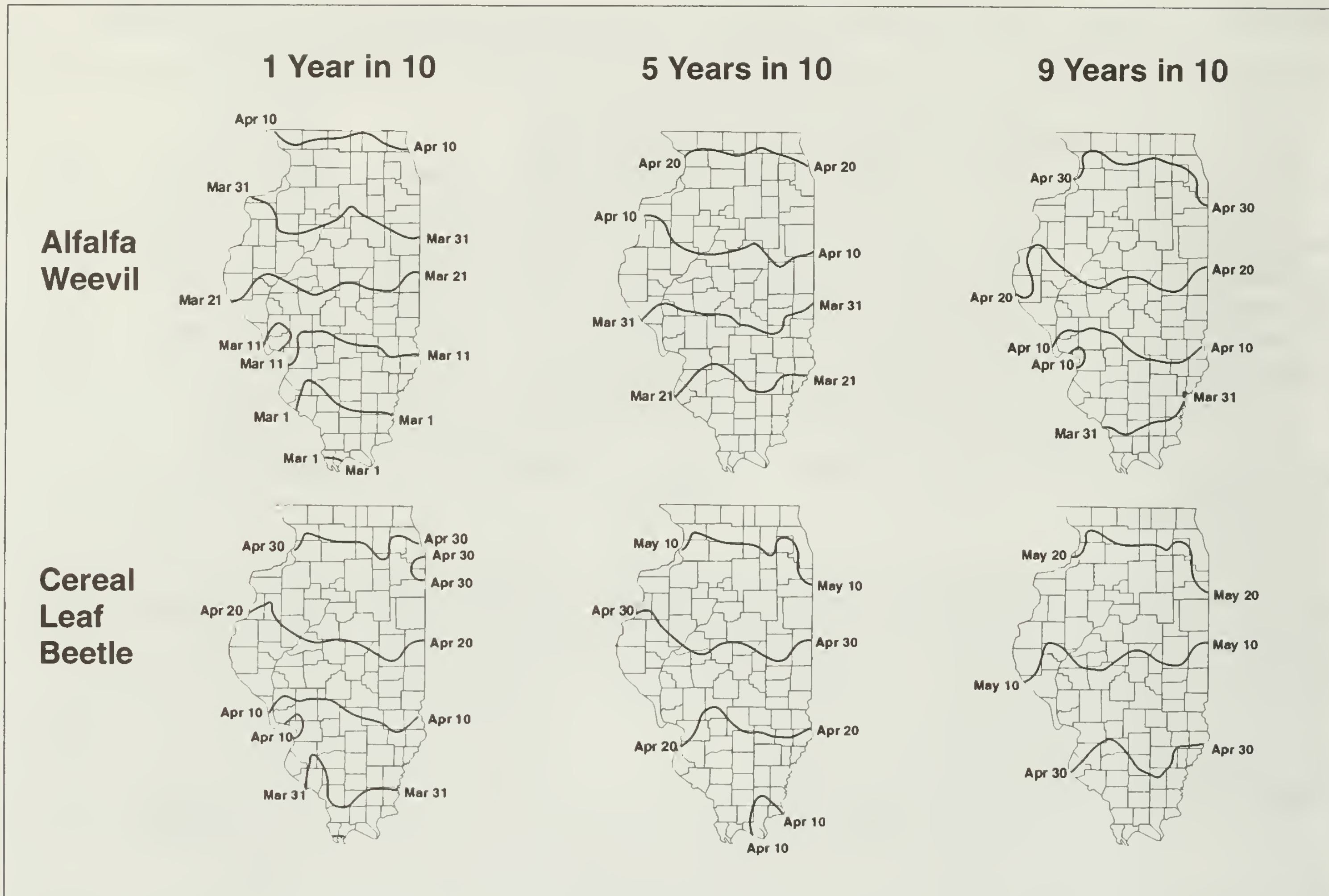


Figure 1.11. Probable dates when scouting for alfalfa weevil and cereal leaf beetle should begin.

European corn borer. Adult moths from the overwintering European corn borer larvae (*Ostrinia nubilalis*) begin to emerge after approximately 420 base 50°F IHUs have accumulated since January 1. (Table 1.05). Egg hatch begins approximately 100 IHUs after the eggs are laid, or approximately 736 IHUs from January 1. Egg survival is reduced when maximum temperatures exceed 97°F (Table 1.06). The first instar larvae have a difficult time surviving when maximum temperatures exceed 90°F.

Moths from the overwintering European corn borer begin to appear (1 year in 10) as early as April 10 in southern Illinois and by May 5 in northern Illinois (Figure 1.12). Adults from the overwintering generation have begun to emerge by April 30 in the south and by May 20 in the north (9 years in 10). These dates mark the start of the appearance of the first flight of adults. Adults will continue to emerge for 1 to 2 weeks after the earliest appearance.

Corn flea beetle. The overwintering adult corn flea beetle (*Chaetocnema pulicaria*) becomes active after 270 base 61°F IHUs have accumulated from January 1. Large populations of the corn flea beetle may be expected when the December, January, and February average temperature is greater than 33°F. Small populations may be expected if the December, January, and February mean temperature is less than 27°F.

The corn flea beetle reaches the adult stage as early as April 20 in the south and May 10 in the north (1 year in 10; Figure 1.13). Nine years in 10, the corn flea beetle reaches the adult stage by May 20 in the south and June 9 in the north. Normally, the adult stage of the corn flea beetle is reached by April 30 in the south, May 15 in central Illinois, and May 25 in the north.

Disease Environmental Thresholds

Disease infestations are influenced by both temperature and humidity. Some diseases occur under warm, humid conditions, others under hot, dry conditions. Thresholds that define hot, warm, cool, and cold growing-season temperatures and high, moderate, and low humidity conditions are presented in Table 1.07. These data can be used in conjunction with cli-

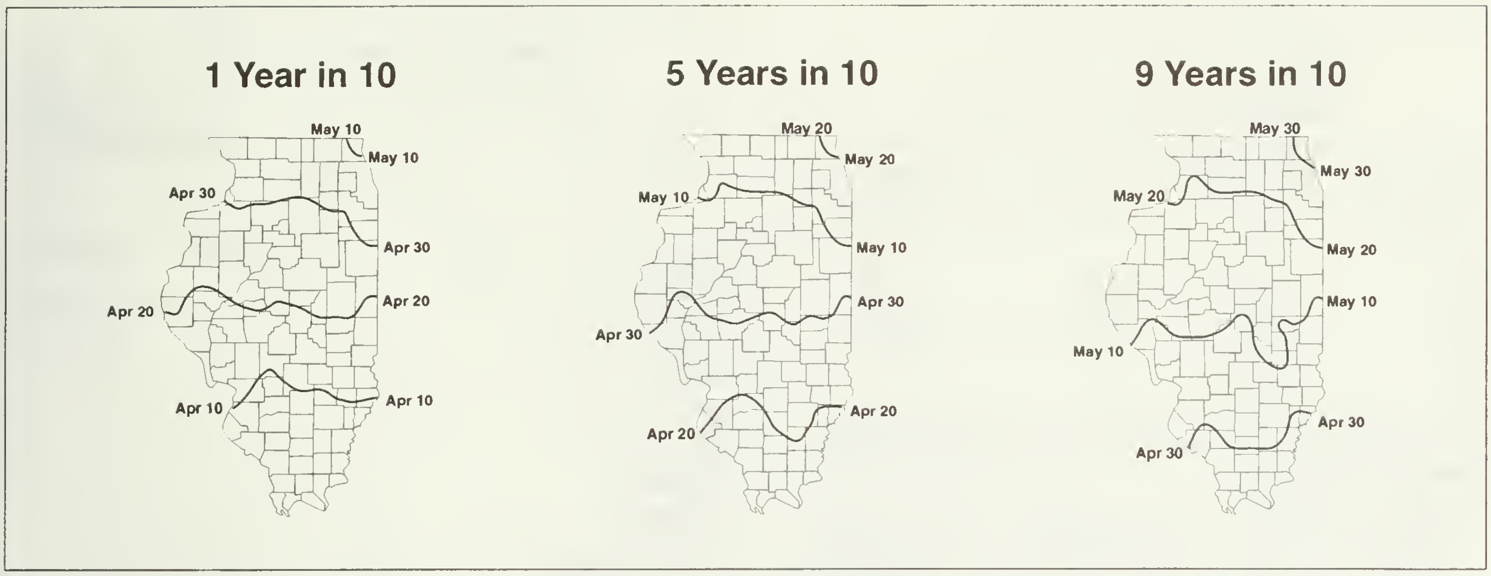


Figure 1.12. Probable dates of the first appearance of the adult European corn borer.

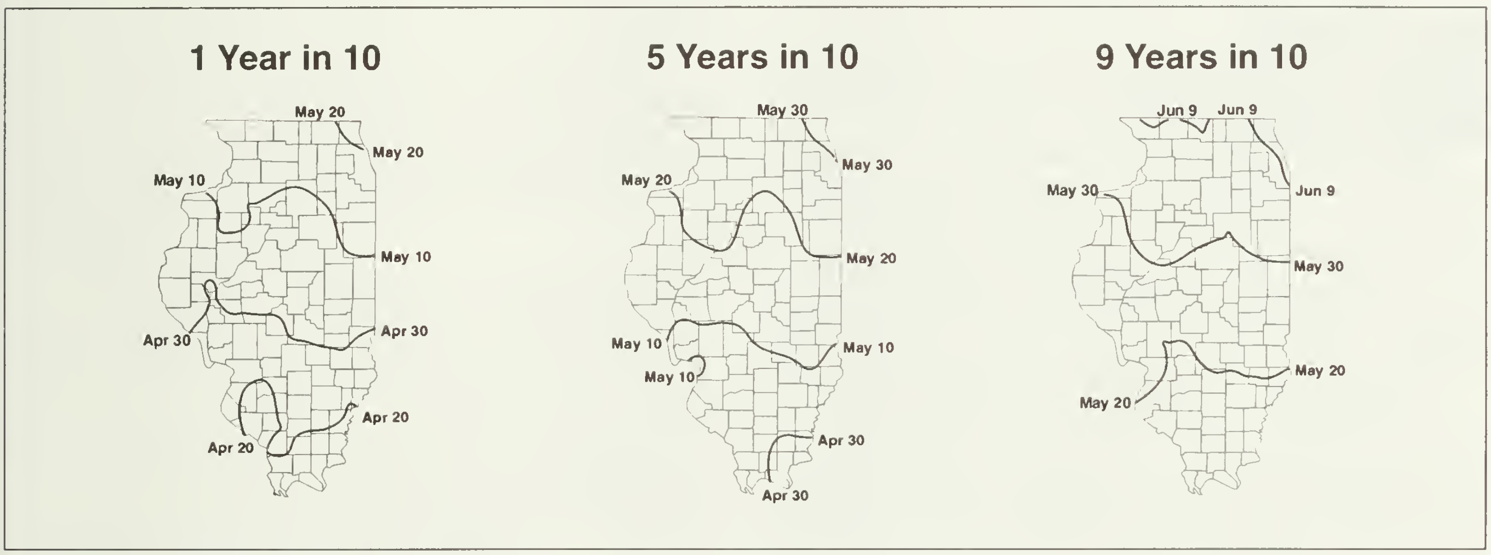


Figure 1.13. Probable dates of the first appearance of the adult corn flea beetle.

mate maps and the *Field Crop Scouting Manual* to evaluate the risks of disease in a given area. When coupled with weather conditions during the current year and climate probabilities, disease risk for a given year may be estimated along with the probable time of disease expression.

Mean daily relative humidities exceeding 85 percent favor the development of many diseases. Normally, there are 2 or 3 days each month when the mean daily relative humidity exceeds 85 percent (Table 1.08). In August and September, an east–west relative humidity gradient exists, and more days with mean daily relative humidity exceeding 85 percent occur in the western part of the state. July is a transition month, with the most days with mean daily relative humidity greater than 85 percent occurring in the west-central region.

Table 1.07. Temperature and Humidity Classifications for Disease Infestation Conditions During the Illinois Growing Season

Temperature conditions	Temperature (°F)	Humidity conditions[a]	Relative humidity (%)
Hot	>82	High	>85
Warm	72–82	Moderate	50–85
Cool	59–71	Low	<50
Cold	<59		

[a]All humidity conditions can be experienced in the different temperature conditions.

Table 1.08. Number of Days with Relative Humidity Exceeding 85 Percent During the Illinois Growing Season

	Days with daily mean relative humidity > 85 percent		
Month	1 year in 10	5 years in 10	9 years in 10
April	2	3	4
May	2	3	4
June	1	2	3
July	1	2	3
August	2	2	3
September	3	3	4

Author

Steven E. Hollinger
Department of Natural Resources
and Environmental Sciences
and Illinois State Water Survey

CHAPTER 2.
CORN

YIELD GOALS

Management decisions are made more easily if the corn producer has set realistic yield goals based on the soil, climate, and available equipment. It is not realistic, for example, to set yield goals of 180 bushels per acre for a soil rated to produce only 130 bushels per acre and from which the highest yield ever produced was 150 bushels per acre. Instead, managing to achieve a realistic yield goal should result in yields greater than the goal in years when conditions are better than average and reduced losses when the weather is unfavorable.

The first step in establishing a yield goal is a thorough examination of the soil type. Information for each soil type, such as the productivity ratings given in Soils of Illinois (Bulletin 778), can be a useful guideline. This information, however, should be supplemented by 3- to 5-year yield records, county average yields, and the yields on neighboring farms. An attempt should be made to ignore short-term weather and to set a goal based on actual yields.

Perhaps the simplest way to set a yield goal is to ignore the highest yield and lowest yield for the past 5 or 6 years that corn was produced in a field and average the remaining yields. It may be appropriate to add 5 to 10 bu/acre to this average to account for better hybrids and management.

HYBRID SELECTION

When tested under uniform conditions, the range in yields among available hybrids is often 50 or more bushels per acre. Thus it pays to spend some time choosing the best hybrids. Maturity, yield for that maturity, standability, and disease resistance are the most important factors to consider when making this choice.

Concern exists with what many consider to be a lack of genetic diversity among commercially available hybrids. Although it is true that a limited number of genetic pools, or populations, were used to produce today's hybrids, it is important to realize that these pools contain a tremendous amount of genetic diversity. Even after many years of breeding, there is no evidence that this diversity has been fully exploited. In fact, a number of studies have shown that breeding progress for most traits is not slowed even after a large number of cycles of selection. Continued improvements in most desirable traits are evidence that this is true. Many of today's hybrids are substantially better than those only a few years old. For this reason, some producers feel that a hybrid "plays out" within a few years. Actually, the performance of a given hybrid should remain constant over the years; but comparison with newer and better hybrids may make it appear to have declined in yielding ability.

Despite considerable genetic diversity, it is still possible to buy the same hybrid from several different companies. This happens when different companies buy the same inbreds from a foundation seed company that has a successful breeding program, or when hybrid seed is purchased on the wholesale market, then resold under a company label. In either case, hybrids are being sold on a nonexclusive basis, and many companies simply put their own names and numbers on the bags of seed.

Many producers, however, would like to avoid planting all their acres to the same hybrid. One way to do this is to buy from only one company, though this may not be the best strategy if it discourages looking at the whole range of available hybrids. Another way of ensuring genetic diversity is to use hybrids with several different maturities. Finally, many dealers have at least some idea of what hybrids are very similar or identical and can provide such information if asked.

It is also important to remember that genetics are only part of the performance potential of any hybrid. The way hybrid seed is produced—the care in

detasseling, harvesting, drying, grading, testing, and handling—can and does have a substantial effect on its performance. Be certain that the seed being bought was produced in a professional manner.

Maturity is one of the important characteristics used in choosing a hybrid. Hybrids that use most of the growing season to mature generally produce higher yields than those that mature more quickly. The latest-maturing hybrid should reach maturity at least 2 weeks before the average date of the first killing freeze (32°F), which occurs about October 8 in northern Illinois, October 18 in central Illinois, and October 25 in southern Illinois. Physiological maturity is reached when kernel moisture is 30 to 35 percent; it is easily identified by the appearance of a black layer on the base of the kernel where it attaches to the cob. The approach to maturity also can be monitored by checking the "milk line," which moves from the crown to the base of the kernel as starch is deposited. The kernel is mature about the time this milk line disappears at the base of the kernel.

Although full-season hybrids generally produce the highest yields, most producers choose hybrids of several different maturities. This practice allows harvest to start earlier and also reduces the risk of stress damage by lengthening the pollination period.

Most farmers and seed companies describe the maturity of a particular hybrid in terms of "days." This designation does not predict how many days the hybrid will take to produce a crop. Rather, it refers to a "relative maturity" rating based on comparison with hybrids of known maturity. This rating is useful, therefore, only as a comparative measurement—it tells us whether a hybrid will mature earlier or later than another hybrid.

A more precise method of describing the maturity of a corn hybrid is to define the accumulated temperature needed for that hybrid to reach maturity. Research has shown that the development of the corn plant follows very closely the accumulation of average daily temperatures during the plant's life. This accumulation is calculated as "growing degree days" (GDD). The GDD concept has been very useful in knowing how the crop will respond to temperatures and in helping to fit hybrids into situations where expected GDD accumulations are known from weather records.

The following formula can be used to calculate GDD accumulated on any given day:

$$\text{GDD} = \frac{\text{H} + \text{L}}{2} - 50°\text{F}$$

with H being the high temperature for the day (but no higher than 86°F) and L the low temperature (but no lower than 50°F). For example (see the following table), if the daily high temperature were 95°F, substitute 86°F, the cutoff point for high temperatures. If the daily low temperature were 40°F, substitute 50°F, the cutoff point for low temperatures. These high and low cutoff temperatures are used because growth rates do not increase above 86°F or decrease below 50°F.

The following figures are examples of daily high and low temperatures and the resulting GDD, calculated using the GDD formula:

Daily temperature		
High	Low	GDD
80	60	20
60	40	5
95	70	28
50	35	0

It is useful to keep a running total of daily GDD from the time of planting. For a full-season hybrid grown in central Illinois, the following table gives the approximate GDD required to reach certain growth stages:

Stage	GDD
Emergence	120
Two-leaf	200
Six-leaf (tassel initiation)	475
Ten-leaf	740
Fourteen-leaf	1,000
Tassel emergence	1,150
Silking	1,400
Dough stage	1,925
Dented	2,450
Physiological maturity (black layer)	2,700

Corn hybrids grown in Illinois have GDD requirements ranging from 2,300 to 2,400 for early hybrids grown in the northern part of the state, to 2,800 to 2,900 for late hybrids grown in the southernmost part of the state. The proportion of total required GDD needed to reach each stage from the previous stage is relatively similar for different maturities, but later-maturing hybrids tend to use a larger proportion of their required GDD to reach silking than do early-maturing hybrids; the number of GDD required from pollination to "natural" physiological maturity is relatively constant among hybrids.

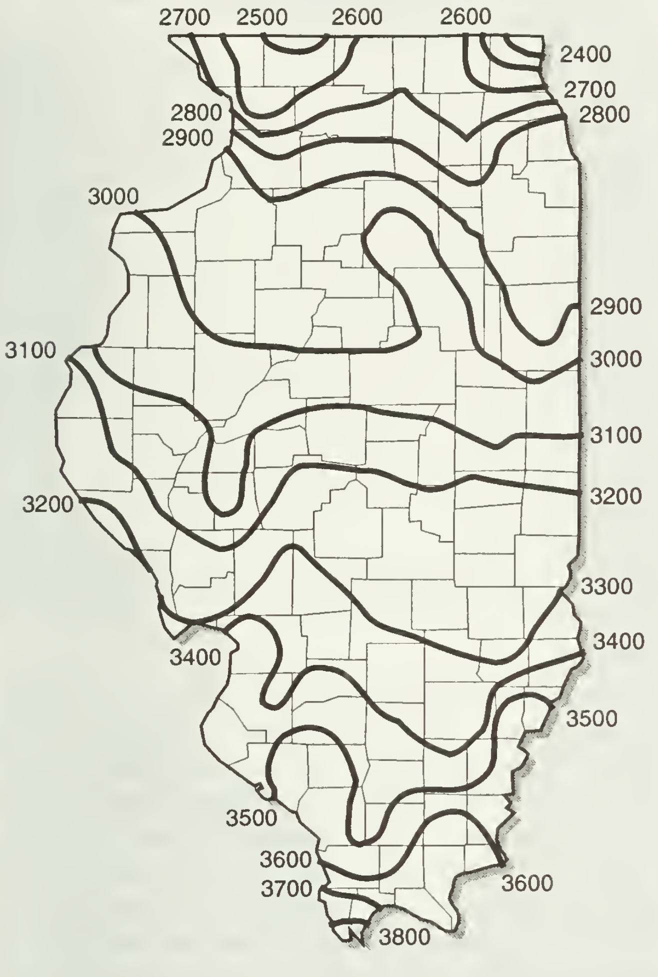


Figure 2.01. Average number of growing degree days (base 50°F from May 1 through September 30) based on temperature data provided by Midwestern Climate Center, 1961–1990. See Chapter 1 for more information on GDD accumulations in Illinois.

A full-season hybrid for a particular area generally matures in several hundred fewer GDD than the number given in Figure 2.01. Thus, a full-season hybrid for northern Illinois would be one that matures in about 2,500 GDD, while for southern Illinois a hybrid that matures in about 2,900 GDD would be considered full season. This GDD "cushion" reduces the risk of frost damage and also allows some flexibility in planting time; it may not be necessary to replace a full-season hybrid with one maturing in fewer GDD unless planting is delayed until late May or early June.

In some recent work in Indiana and Ohio, researchers found that the GDD requirement for corn hybrids decreased when planting was later than May 1. For each day that planting was delayed after May 1, the reduction in GDD requirement was about 6.5 GDD; thus, a 2,700 GDD corn hybrid planted on May 20 requires only 2,700 – (20 × 6.5) = 2,570 GDD. While the actual decrease in GDD varied somewhat among years, the fact that there is an expected decrease indicates that changing to a shorter-season hybrid should be delayed even more. This decrease in GDD requirement, however, usually comes at the cost of decreased yield; planting on time is still an important goal.

After yield and maturity, resistance to lodging is probably the next most important factor in choosing a hybrid. Because large ears tend to draw nutrients from the stalk, some of the highest-yielding hybrids also have a tendency to lodge. Such hybrids may be profitable due to their high yields, but they should be watched closely as they reach maturity. If lodging begins, or if stalks become soft and weak (as determined by pinching or pushing on stalks), then harvesting these fields should begin early.

Resistance to diseases and resistance to insects are important characteristics in a corn hybrid. Leaf diseases are easiest to spot, but stalks also should be checked for diseases. Resistance to insects such as the European corn borer also is being incorporated into modern hybrids. Another useful trait is the ability of the hybrid to emerge under cool soil conditions, which is especially important in reduced- or no-till planting.

Seed companies have recently begun to release hybrids containing a number of different "genetically engineered" traits. All of these are single-gene traits, and the gene was inserted into the corn plant from another organism; for example, the *Bt* gene came from a bacterium. This technology holds a great deal of potential, since it means that genes found anywhere in the world, or even genes produced in the laboratory, can be put into corn. Most of the genes released in this way so far have been for resistance to insects or herbicides, and they have been incorporated into commercial hybrids using backcrossing. Backcrossing takes time, and except for the inserted gene, the product is no better than the parent that the gene was crossed into, so this technique slows the pace of overall genetic improvement. Another drawback to genetic engineering is that complex traits such as yield or growth rate are usually controlled by many genes that interact with one another. Such groups of interacting genes will likely be difficult to isolate and transfer, so progress for traits such as yield will continue to depend on traditional methods of breeding.

With the many hybrids being sold, choosing the best one is difficult. An important source of information on hybrid performance is the annual report *Performance of Commercial Corn Hybrids in Illinois*, published as a newspaper insert in the fall in *Illinois Agri-News*, as a separate report available in Extension

Table 2.01. Days and Percentages of Calendar Days Available for Field Operations in Illinois[a]

	Northern Illinois		Central Illinois		Southern Illinois	
Period	Days	%	Days	%	Days	%
April 1–20[b]	5.8	29	4.2	21	2.6	13
April 21–30[c]	3.5	35	3.1	31	2.6	26
May 1–10[c]	5.8	58	4.3	43	3.5	35
May 11–20[c]	5.5	55	5.0	50	4.4	44
May 21–30[c]	7.4	74	5.8	58	5.4	54
May 31–June 9[c]	6.0	60	5.4	54	5.6	56
June 10–19[c]	6.0	60	5.4	54	5.8	58

[a]Summary prepared by R.A. Hinton, Department of Agricultural and Consumer Economics of the University of Illinois. Data are from the Cooperative Crop Reporting Service's estimates of favorable work days, 1955–1975. The summary is the mean of favorable days omitting Sundays, less one standard error, representing the days available 5 years out of 6.
[b]20 days.
[c]10 days.

offices, and on the Web at <http://w3.aces.uiuc.edu/CropSci/research/vt/index.html>. This report summarizes hybrid tests run each year in nine Illinois locations and includes yield information from the previous 2 years. The report gives data on yields, kernel moisture, and lodging of hybrids. Other sources of information include your own tests and tests conducted by seed companies, neighboring producers, and Extension staff.

Producers should see the results of as many tests as possible before choosing a hybrid. Good performance for more than one year is an important criterion. Hybrid choice should not be based on the results of only one "strip test." Such a test uses just one strip of each hybrid; the difference between two hybrids may therefore be due to location in the field rather than an actual genetic difference.

Planting Date

Long-term studies show that the best time to plant corn in Illinois is the last week of April, with little or no yield loss when planting is within a week on either side of this period. Weather and soil conditions permitting, planting should begin sometime before this date to allow for days when fieldwork is impossible (Table 2.01). Corn that is planted 10 days or 2 weeks before the optimal date may not yield quite as much as that planted on or near the optimal period, but it will often yield more than that planted 2 weeks or more after the optimal period.

In general, yields decline slowly as planting is delayed up to May 10. From May 10 to May 20, the yield declines about one-half bushel for each day that planting is delayed. This loss increases to 1 to 1½ bushels per day from May 20 to June 1, with greater reductions in northern than in southern Illinois. After June 1, yields decline very sharply with delays in planting. The latest practical date to plant corn ranges from about June 15 in northern Illinois to July 1 in southern Illinois. If you plant this late, expect only 50 percent of the normal yield.

Early planting results in drier corn in the fall, allows for more control over the planting date, and allows for a greater choice of maturity in hybrids. In addition, if the first crop is damaged, the decision to replant often can be made early enough to allow use of the first-choice hybrid. Of course, early planting has some disadvantages: (1) cold, wet soil may produce a poor stand; (2) weed control may be more difficult; and (3) plants may suffer from frost. Improved seed vigor, seed treatments, and herbicides have greatly reduced the first two hazards, and the fact that the growing point of the corn plant remains below the soil surface for 2 to 3 weeks after emergence minimizes the third hazard. Because this part of the plant is below the surface, it is seldom damaged by cold weather unless the soil freezes. Even when corn is frosted, therefore, the probability of regrowth is excellent. For these reasons, the advantages of early planting outweigh the disadvantages.

The lowest temperature at which corn germinates is about 50°F. You can take your own soil temperature or use reported measurements that are taken beneath bare soil. Soil temperature, however, is not the only consideration in deciding when to start planting. A more important consideration may be the condition of the soil: It generally is a mistake to till and plant when soils are wet, and the advantages of early planting may well be lost to soil compaction and other problems associated with "mudding in" corn, whether using conventional tillage or no-till techniques. If the weather conditions have been warm and dry enough to result in workable soils by early April, then planting can probably begin by April 10 or 15 with little danger of loss. The weather may change after planting, however, and a return to average temperatures means slow growth for corn planted this early. It may be desirable to increase seeding rates by 1,000 to 2,000 seeds per acre for April planting, mainly to allow for greater losses and to take advantage of the more favorable growing conditions that the crop is likely to

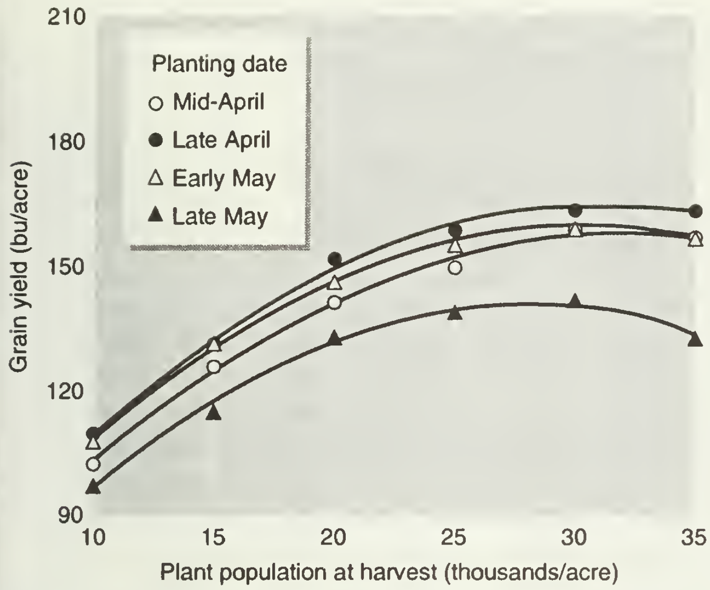


Figure 2.02. Response of corn planted at different times to plant population. Data are averages of two hybrids planted at two locations (Monmouth and DeKalb) for 4 years.

encounter. Recent research shows little change in optimal plant population when planting time ranges from mid-April through early May (Figure 2.02).

With typical spring weather, preparation for corn planting can begin sometime in the first half of April. Delays due to low soil temperature (below 50°F) should be considered only if the weather outlook is for continued cold air temperatures. After April 20, soil temperature should be ignored as a factor, and corn should be planted as soon as soil conditions allow. Low-lying areas (such as river bottoms) may be planted last because they warm up more slowly and are more prone to late freezes.

When planting begins in April, it is generally best to plant very-full-season hybrids first, but planting the midseason and early hybrids in sequence tends to "stack" the times of pollination and harvest of the different maturities. It is probably better to alternate between early and midseason hybrids after the full-season hybrids are planted. This practice helps to spread both pollination risks and the time of harvest.

Planting Depth

Ideal planting depth varies with soil and weather conditions. Emergence is more rapid from relatively shallow-planted corn, so early planting should not be as deep as later planting. For normal conditions, an ideal depth is 1½ to 2 inches. Early-planted corn should be in the shallower end of this range. Later in the season, when temperatures are higher and evaporation is greater, planting as much as 2½ inches deep to reach moist soil may be advantageous.

Depth-of-planting studies show not only that fewer plants emerge when planted deep but also that those emerging often take longer to reach the pollinating stage and may have higher moisture in the fall.

Plant Population

The goal at planting time is to establish the highest population per acre that can be supported with normal rainfall without excessive lodging, barren plants, or pollination problems. One way to know when the plant population in a field is near the optimum is to estimate the average ear weight. Check at maturity, or estimate by counting kernels (number of rows multiplied by number of kernels per row) once the kernel number is set. Most studies in Illinois suggest that the optimal plant population produces ears weighing about one-half pound and having about 640 kernels. A half-pound ear should shell out about 0.4 pound of grain at 15 percent moisture.

The data shown in Figure 2.02 were used to generate Table 2.02 which gives expected yield at different plant populations planted on different dates. One important finding in this study was that the plant population producing the highest yield did not change with the planting date; there is no reason to increase or decrease plant population when planting early or late, except that a higher percentage of seeds may establish plants with later planting, and the number of seeds dropped thus may decrease a bit when planting is late.

The data in Table 2.02 can be used to make replanting decisions (see the text section on replanting). The latest planting in this study was late May, however, so effects of replanting in June cannot be accurately determined from this work. Note that the highest yields were from populations around 30,000 per acre, which produced ears with less than 0.4 pound of grain on average. Though the eight trials combined here were not always high-yielding (the study included the drought year of 1988), there is little reason to decrease plant populations below the upper 20,000s under productive conditions, at least in the northern half of the state.

More recent studies have confirmed the need for relatively high plant populations to maximize yields. Figure 2.03 contains the results of studies conducted at four locations, with data averaged over 4 years (1991–1994) and six hybrids. The plant populations were established by thinning after emergence and thus are very close to harvest populations. These results show rather clearly that plant populations need to be in the range of 25,000 to 30,000 for best yields under most conditions.

Table 2.02. Percent of Maximum Yield Expected from Planting on Different Dates and at Different Plant Populations Using Data Generated from the Results in Figure 2.02

	Plant population per acre										
Planting date	10,000	12,500	15,000	17,500	20,000	22,500	25,000	27,500	30,000	32,500	35,000
	% of maximum yield expected										
April 10	62	70	76	82	86	90	92	94	94	94	93
April 15	65	73	79	84	89	92	95	97	97	97	95
April 20	67	74	81	86	91	94	97	98	99	99	97
April 25	68	75	82	87	92	95	98	99	100	100	98
April 30	68	75	82	87	92	95	98	99	100	100	98
May 4	67	75	81	86	91	94	97	99	99	99	97
May 9	65	73	79	85	89	93	95	97	97	97	96
May 14	63	70	76	82	86	90	92	94	95	94	93
May 19	59	66	73	78	83	86	89	90	91	91	89
May 24	54	62	68	74	78	82	84	86	86	86	85
May 29	49	56	63	68	73	76	79	80	81	80	79

The same data, but plotted with individual years and locations separately in Figure 2.04, show this more directly. Optimal yields and plant populations were calculated as the point at which the last addition of seed just paid for itself in extra yield. We can conclude from these data that, when weather conditions are favorable for high yields, we need high plant populations to reach those yield potentials. Optimal plant populations were above 25,000 for all but one of the 16 trials conducted.

The development of variable-rate planter drives means that we are now able to change planting rates as we drive across a field. Unfortunately, we don't have good guidelines to tell us that different parts of a field should have different plant populations. The data in Figure 2.04 at least hint that higher-yielding areas may need more plants. But using a yield monitor in a field to identify low-yielding areas and then reducing plant population there is counterproductive if low yields result from low plant populations, as is often the case. Limited research to date has indicated that most productive fields in Illinois will probably

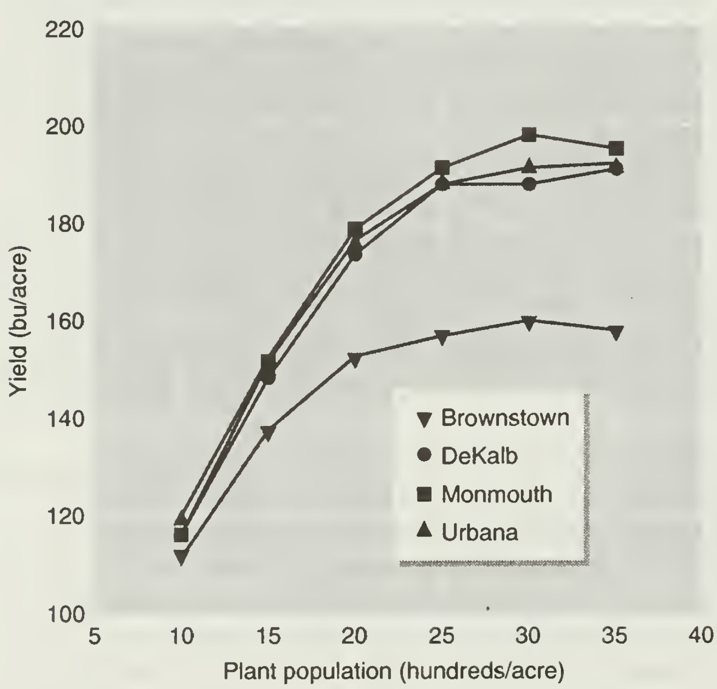


Figure 2.03. Yield response of corn to plant population at four Illinois locations. Data are averages over 4 years (1991–1994) and six hybrids.

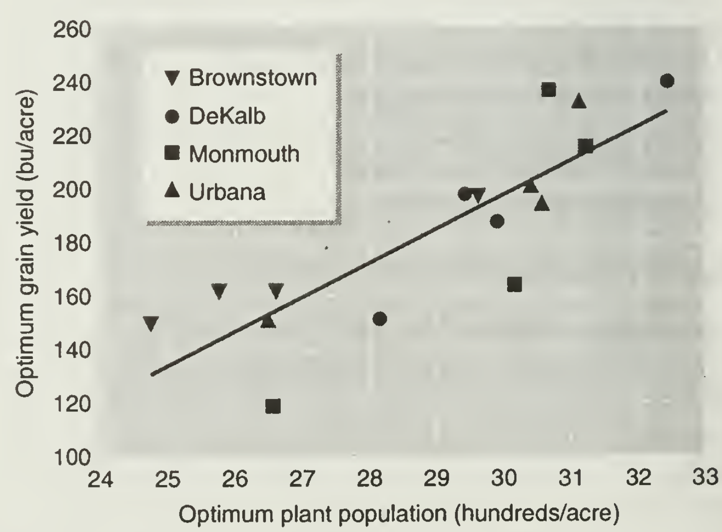


Figure 2.04. Optimal economic yields and plant populations, calculated from the individual year–location data shown in Figure 2.03. Data are averages over six hybrids.

show little return from varying populations. Fields with both heavy and light soils may benefit, especially if experience shows that plants in the lighter soils are often barren or that yields are usually low. In more uniform fields, it is more important to have populations high enough for best yields, and populations should probably not be changed more than 10 percent or so from the normal population when the planting rate is varied. It is very easy to test the effects of variable-rate population: simply vary the population while driving in one direction and leave it uniform when driving the other direction, thus stripping the field with VRT and uniform populations. Check yields of these contrasting strips with a yield monitor to see if VRT plant population increases yield.

Two very important controllable factors influencing the efficiency of water use are soil fertility and weeds. Keep the fertility of the soil at optimum levels and the weed population low.

Other factors that are important include these:

1. **Hybrid selection.** Though hybrids differ in tolerance to the stress of high populations, such differences can be difficult to predict. Most modern hybrids can, however, tolerate populations of 23,000 to 25,000 per acre on most Illinois soils. Most need higher populations—up to 30,000 per acre—to produce the best yields, especially on more productive soils.

2. **Planting date.** Early planting enables the plant to produce more of its vegetative growth during the long days of summer and to finish pollinating before the hot, dry weather that is normal for late July and early August. Early planting usually produces larger root systems as well. In the study reported in Figure 2.02 and Table 2.02, however, planting date had little effect on optimal plant population.

3. **Row spacing.** The more uniform distribution of plants grown in narrow rows may improve the efficiency of water use. Earlier canopy development with narrow rows may, however, also dry soils more quickly.

4. **Insect and disease control.** The harvest population is always less than the number of seeds planted. Insects, diseases, adverse soil conditions, and other hazards take their toll. Expect from 10 to 20 percent fewer plants at harvest than seeds planted (Table 2.03).

Row Spacing

Because a clear yield advantage comes from using a row spacing of less than 40 inches, most producers have reduced row spacing. More than 80 percent of

Table 2.03. Planting Rate That Allows for a 10 or a 15 Percent Loss from Planting to Harvest

Plants per acre at harvest	Seeds per acre at planting time	
	10% loss	15% loss
20,000	22,200	23,500
22,000	24,400	25,900
24,000	26,700	28,200
26,000	28,900	30,600
28,000	31,100	32,900
30,000	33,300	35,300
32,000	35,600	37,600
34,000	37,800	40,000

the corn acres in Illinois are planted in 30-inch rows, with most of the rest in 36-inch rows, and with increasing acreage in rows less than 30 inches apart. Very recently, there has been a great increase in interest in rows narrower than 30 inches apart. This interest has grown for a number of reasons: Reports from the northern part of the Corn Belt (Minnesota and Michigan) have been very positive; newer hybrids can, unlike those used in 20-inch-row experiments in the 1960s, stand and yield well at the higher populations that normally accompany narrow rows; and the required equipment is more widely available.

Although some of our work in Illinois in the 1980s had shown yield increases of 5 to 8 percent when row spacing was reduced from 30 to 20 inches, more recent results have not shown as much yield increase. Figure 2.05 shows the response to row spacing and plant population in a series of studies conducted from 1992 to 1994 at Monmouth and DeKalb, Illinois. Data are averaged over the 3 years and two locations as well as over two hybrids, which differed little in their response. At low populations, narrow rows produced higher yields than wide rows. As plant populations rose above 25,000, however, the yield advantage of 20-inch rows over 30-inch rows disappeared. It may be that the hybrids used in this study were simply able to form a full canopy at high populations, even in 30-inch rows.

Despite some questions about the yield response expected from narrowing the rows to less than 30 inches, some farmers are investing in the equipment needed to make this change. Other benefits may include slightly more yield stability over a range of weather conditions, better suppression of early-emerging weeds, and the fact that narrower rows

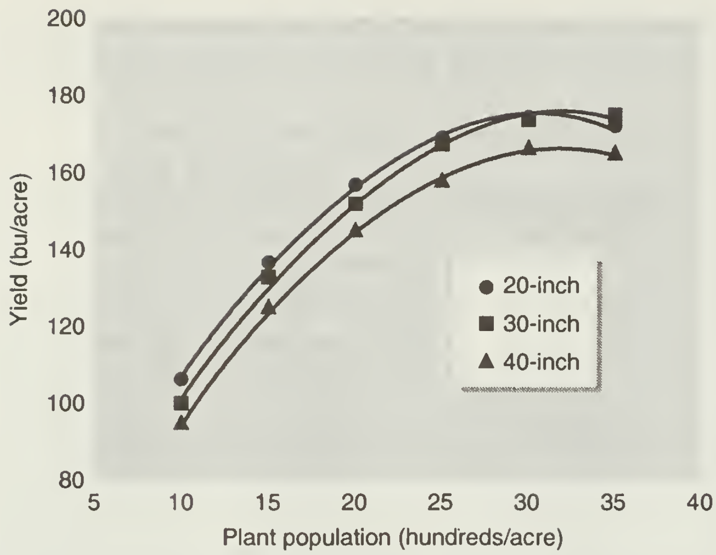


Figure 2.05. Corn response to row spacing and plant population. Data are averaged over 3 years (1992–1994) and two hybrids.

usually mean a decision to use somewhat higher plant populations, which (as Figure 2.03 shows) may produce higher yields—even if these higher yields are a "by-product" of the equipment change.

Plant Spacing in the Row

In recent years a number of researchers have reported that uneven distribution of plants down the row can decrease yield. The evenness of distribution of plants in the row can be measured using a statistic called the *standard deviation*, which is calculated from measurements of individual plant-plant distances, and which ranges from zero with perfect spacing to 6 inches or more where stands are very unevenly distributed. Standard deviation tends to increase with lower plant populations, because missing plants in such cases leave a large gap in the row. Doubles—two plants in the space usually occupied by one plant—also increase standard deviation.

Table 2.04 gives the results of a series of planter speed studies that were conducted by farmers in east central Illinois. These results showed that, even though planting faster tended to increase the standard deviation of plant spacing, it had little effect on plant population or yield. In only 1 of the 11 trials that were averaged to produce the data in Table 2.04 did faster planting decrease yield, and in that trial faster planting also decreased the plant population. If a planter can drop the intended number of seeds when run at a faster speed, there appears to be little reason to slow it down, unless faster planting causes a lot of variation in the depth of planting. Our general conclusion on the effect of plant distribution in the row may be summed up as follows: *within reason, plant spacing uniformity within the row has little effect on yield if plant population is adequate for high yields.*

Table 2.04. Effect of Planter Speed on Plant Spacing Variability (Standard Deviation), Plant Population, and Yield

Planter speed (mph)	Standard deviation (in.)	Plant population (per acre)	Yield (bu/ac)
3	2.87	27,230	153
5	2.99	27,370	152
7	3.22	27,000	153

Data are averages of 11 trials conducted by farmers in East Central Illinois, 1994–96.

Crop Canopy

Figure 2.06 illustrates the importance of canopy cover during grainfill. These data were taken in 1992–1994 from the plant population trial at Urbana. They help explain some of the variability in response to both row spacing and plant population. Though there may be exceptions, such as when pollination fails or pests are severe, it is clear that forming and maintaining a canopy that intercepts at least 95 percent of the sunlight after pollination is essential for high corn yields. In a real sense, managing row spacing and plant

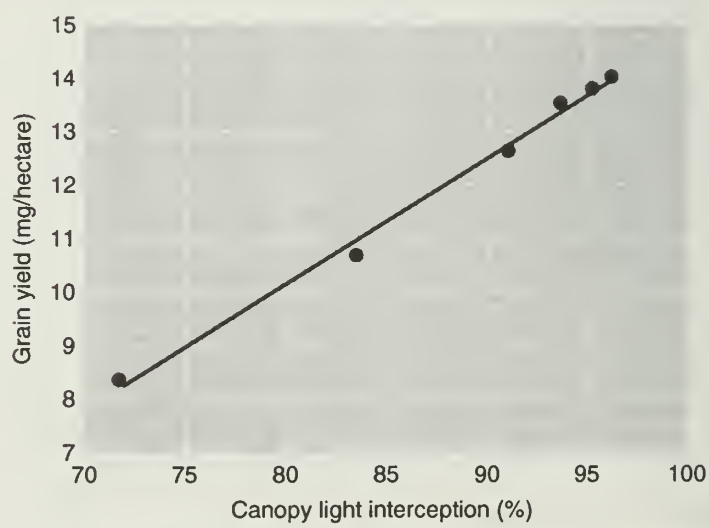


Figure 2.06. Relationship between light interception during grainfill and corn yield. Data are from a plant population trial conducted at Urbana, Illinois, and are averaged over 3 years (1992–1994).

population for a particular corn hybrid should be seen as managing to produce and maintain this canopy.

The success of an attempt to "manage for canopy" can best be measured by looking down the rows at about noon on a clear day in early August. Although you probably can't tell whether light interception is 95 percent or slightly less than that, streaks of sunlight or many large patches of sunlight on the soil beneath the canopy indicate that you probably have not optimized the management of that particular hybrid for that field and weather.

Stand Counting

Though the most common method of taking plant populations has been to count the number of plants in 1/1,000 of an acre, that length of row is small enough that it's easy to bias the count by consciously or unconsciously selecting better places to count. The method described here generally provides more accurate counts. The method uses a measuring wheel, which is available for $60 to $100. Here's how it works:

1. Walk out into the field, set the measuring wheel to zero, and push it down a row while counting plants. It's much faster to count plants in groups of three.
2. When you've counted up to 150 plants, stop and note how many feet of travel the measuring wheel has recorded.
3. Divide the number of feet traveled *into* the following factor to determine plant population:

Row spacing (in.)	Factor
20	3,920,400
22	3,564,000
24	3,267,000
26	3,015,700
28	2,800,300
30	2,613,600
32	2,450,250
34	2,306,100
36	2,178,000
38	2,063,350

For example, if you walked 124 feet while counting 150 plants in 30-inch rows, the population is 2,613,600/124 = 21,077. Write down the factor for your row spacing, and enter it into calculator memory to use while you're taking counts.

Because a longer row length is counted and it is more difficult to bias the count, this method requires fewer counts per acre than the older method. If stands are reasonably uniform, you can probably get a good estimate of plant population by taking one count for each 5 to 10 acres in the field. If the first two or three counts are very different from one another, then more counts may be needed.

Replanting

Although it is normal that 10 to 15 percent of planted seeds fail to establish healthy plants, additional stand losses due to insects, frost, hail, flooding, or poor seedbed conditions may call for a decision on whether or not to replant a field. The first rule in such a case is not to make a hasty decision. Corn plants often outgrow leaf damage, especially when the growing point, or tip of the stem, is protected beneath the soil surface or up to about the six-leaf stage. If new leaf growth appears within a few days after the injury, the plant is likely to survive and produce near-normal yields.

When deciding whether or not to replant a field, assemble the following information: (1) original planting date; (2) possible replanting date and expected plant stand; and (3) cost of seed and pest control for replanting.

When the necessary information on stands and planting and replanting dates has been assembled, use Table 2.02 to determine both the loss in yield to be expected from the stand reduction and the yield expected if the field is replanted.

To use Table 2.02, locate the expected yield of the reduced plant stand by reading across from the original planting date to the plant stand after injury. Then locate the expected replant yield by reading across from the expected replanting date to the stand that would be replanted. The difference between these numbers is the percent yield increase (or decrease) to be expected from replanting. For example, corn that was planted on April 25 but has a plant stand reduced to 15,000 by cutworm injury would be expected to yield 82 percent of a normal stand. If such a field were replanted on May 19 to establish 30,000 plants per acre, the expected yield would be 91 percent of normal. Whether it would pay to replant such a field depends on whether the yield increase of 7 percentage points would repay the replanting costs. In this example, if replanting is delayed until near the end of May, the yield increase to be gained from replanting disappears.

Weather Stress in Corn

Corn frequently encounters some weather-related problems during the growing season. The effect of such problems differs with the severity and duration of the stress and the stage of crop development at the time of the stress. Some possible stress conditions and their effects on corn growth and yield follow:

A. **Flooding.** The major stress caused by flooding is simply a lack of oxygen needed for the proper function of the root system. When plants are very small, generally they are killed after about 5 or 6 days of being submerged. Death occurs more quickly if the weather is hot, because high temperatures speed up the biochemical processes that use oxygen, and warm water has less dissolved oxygen. Cool weather, by contrast, may allow plants to live for more than a week under flooded conditions. When plants reach the six- to eight-leaf stage, they can tolerate a week or more of standing water, though total submergence may increase disease incidence, and plants suffer from reduced root growth and function for some days after the water recedes. Tolerance to flooding generally increases with age, but reduced root function from lack of oxygen is probably more detrimental to yield before and during pollination than during rapid vegetative growth or during grainfill.

B. **Hail.** The most common damage from hail is loss of leaf area, though stalk breakage and bruising of the stalk and ear can be severe. Loss charts based on leaf removal studies generally confirm that defoliation at the time of tasseling causes the greatest yield loss, while loss of leaf area during the first month after planting or when the crop is near maturity generally causes little yield loss. Loss of leaf area in small plants usually delays their development, however, and plants that experience hail may not always grow normally afterward.

C. **Cold injury.** Corn is of tropical origin and is not especially tolerant of cold weather. Although the death of leaves from frost is the most obvious type of cold injury, leaves are damaged by temperatures below the low 40s, and photosynthesis can be reduced even if the only symptom is a slight loss of leaf color. The loss of leaves from frost is generally not serious when it happens to small plants, though such loss delays plant development and could delay pollination to a less favorable (or, infrequently, a more favorable) time. Frost injury symptoms may appear on leaves even when nighttime temperatures do not fall below the mid-30s; radiative heat loss can lower leaf temperatures to several degrees below air temperatures on a clear, calm night. If frost kills leaves before physiological maturity (black layer) in the fall, sugars usually can continue to move from the stalk into the ear for some time, although yields generally are lowered, and harvest moisture may be high due to high grain moisture at the time of frost and slow drying rates that usually follow premature death.

D. **Drought.** Through the late vegetative stage (the end of June in normal years), corn is fairly tolerant of dry soils, and mild drought during June may even be beneficial because roots generally grow downward more strongly as surface soils dry, and the crop benefits from the greater amount of sunlight that accompanies dry weather. During the 2 weeks before and 2 weeks following pollination, corn is very sensitive to drought, however, and dry soils during this period can cause serious yield losses. Most of these losses are due to failure of pollination, and the most common cause is the failure of silks to emerge from the end of the ear. When this happens, the silks do not receive pollen; thus the kernels are not fertilized and do not develop. Drought later in grainfill has a less serious effect on yield, though root function may decrease and kernels may not fill completely.

E. **Heat.** Because drought and heat usually occur together, many people assume that high temperatures are a serious problem for corn. In fact, corn is a crop of warm regions, and temperatures lower than 100°F usually do not cause much injury if soil moisture is adequate. Extended periods of hot, dry winds can cause some tassel "blasting" and loss of pollen, but pollen shed usually takes place in the cooler hours of the morning, and conditions severe enough to cause this problem are unusual in Illinois. There is evidence that hybrids vary in their sensitivity to both heat and drought, though genetic drought tolerance usually means some loss in yield potential. As a result,such hybrids may not be good choices for average conditions.

Estimating Yields

Making plans for storing and marketing the crop often calls for estimating yields before the corn is harvested. Such estimates are easier to make for corn than for most other crops because the number of plants or ears per acre can be counted fairly accurately.

Estimating corn yields is done by counting the number of ears per acre and the number of kernels per ear, then multiplying these two numbers to get an estimate of the number of kernels per acre. Next, simply

Table 2.05. Row Length Required to Equal 1/1,000 Acre

Row width	Row length
20"	26'1"
28"	18'8"
30"	17'5"
32"	16'4"
36"	14'6"
38"	13'9"
40"	13'1"

divide by an average number of kernels in a normal bushel to get the yield in bushels per acre.

Corn yields can be estimated after the kernel number is fixed—about 2 weeks after the end of pollination. The following steps are suggested:

1. Walk out in the field a predetermined number of rows and paces. For example, go 25 rows from the edge of the field and 85 paces from the end of the field. If this pattern is not determined beforehand, there is a tendency to stop where the crop looks better than average. Stop exactly where planned.
2. Measure 1/1,000 of an acre (Table 2.05), and count the number of *ears* (not stalks) in that distance. Do not count ears with only a few scattered kernels.
3. Take three ears from the row that was counted. To avoid taking only good ears, take the third, sixth, and tenth ears in the length of row. Do not take ears with so few kernels that they were not included in the ear count.
4. Count the number of rows of kernels and the number of kernels per row on each ear. Multiply these two numbers together for each ear, then average this kernel count for the three ears.
5. Calculate yield using the following formula:

$$\text{bu/acre} = \frac{\text{number of ears per } 1/1{,}000 \text{ acre} \times \text{average number of kernels per ear}}{90}$$

6. To get a reliable average, repeat this process at least once for every 5 acres in a field.

The formula uses the number 90 on the assumption that a bushel of normal-sized seed contains about 90,000 kernels. The zeros are dropped because the plant population is given in thousands per acre.

Specialty Types of Corn

Erratic and generally low world corn prices have resulted in considerable interest among producers in growing various specialty types of corn, either for export or for domestic use. This may mean higher profits if the supply of such types is quite small. Because the total demand might also be quite limited, however, the price advantage may disappear as more producers start growing a particular specialty type. It is therefore important to have other uses for the crop (for example, as livestock feed) and to grow types that do not yield substantially less than normal corn, in the event that the corn cannot be sold for its intended special use.

Many specialty types are grown under contract. The contract buyers often specify what hybrids may or may not be used, and they may specify other production practices to be used. Some contracts also may include pricing information and quality specifications.

Risks associated with growing specialty types of corn vary considerably. Milling companies may buy corn with "food-grade endosperm," requiring only that the grower choose hybrids from a relatively long list of popularly grown hybrids; the risk in this case is small. By contrast, inbreds used to produce some hybrids are not very vigorous, and seed corn production with such inbreds might be very risky. Production contracts in such cases may shift some of the risk to the buyer. In any case, every grower of specialty types of corn should be aware of risks associated with each type.

Fortunately, most of the specialty types of corn that are available require production practices much like those of normal, yellow dent corn. In most cases, pollination with normal corn results in "intermediate" kernel types, which usually lower the value of the corn as a specialty type. Isolation from normal corn, or harvesting the outside rows of the specialty type (where most of the normal pollen would land) and using them for feed or other nonspecialty use, will usually improve the quality of the specialty type.

White corn and **yellow, food-grade** corn are both used for human consumption. Many normal hybrids produce good quality for use as food. White hybrids have not been bred quite as extensively as yellow hybrids, and most of the white hybrids tend to be later in maturity than hybrids commonly grown in northern Illinois. Buyers of food-grade corn may require that grain be dried to a certain moisture content in the field, and that drying temperatures be kept low. **Waxy** corn contains 100 percent amylopectin starch, compared to 75 percent in normal corn. Amylopectin starch has certain characteristics that are useful in

food and industrial products. In contrast, **high-amylose corn** has lower amylopectin, and more than 50 percent amylose, which has different properties than amylopectin, and so has use in a different group of food and industrial products.

In the past few years, **high-oil** corn hybrids have been developed using *topcross* technology, in which male-sterile hybrids are pollinated by 7 to 10 percent of the plants in the field whose pollen carries the high-oil characteristic. Because oil content of grain from these hybrids is 6.5 to 7.5 percent—about double the normal oil content—this grain has higher caloric value for livestock feed. At present, premiums are paid for this grain based on oil content. Because the caloric content of the grain is higher, such hybrids may yield slightly less on average than do their normal-oil counterparts.

Popcorn has very hard endosperm that expands rapidly when water in the endosperm is turned to steam by rapid heating. Most popcorn is produced under contract to a processor. Popping volume is an important characteristic of popcorn hybrids, and premiums may be paid for hybrids that have high popping volume but less yield. There are yellow- and white-hulled popcorn hybrids, as well as types with purple or black seedcoat colors. Most popcorn hybrids are less vigorous than normal corn hybrids, and so are less tolerant of adverse weather. Increasing amounts of popcorn are grown under irrigation.

Author

Emerson D. Nafziger
Department of Crop Sciences

Chapter 3. Soybeans

Planting Date

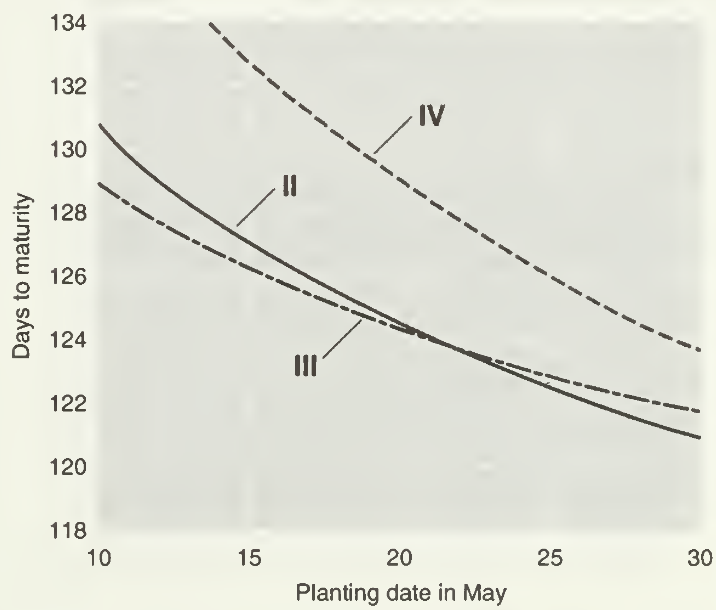
Soybeans generally yield best when planted in May, with full-season varieties tending to yield best when planted in early May. Earlier varieties, however, often yield more when planted in late May than in early May. When the planting of full-season varieties is delayed until late May, the loss in yield is minor compared with the penalty for planting corn late. Therefore, planting soybeans after corn has been planted is accepted and wise.

The loss in yield of soybeans becomes more severe when planting is delayed past early June. The penalty, however, for late-planted corn is proportionally greater, and the danger of wet or soft corn becomes such a threat that soybeans are, under most conditions, a better crop for late planting than corn.

Planting date affects the length of time required for soybeans to mature, with delays resulting in fewer days needed for the plant to complete its life cycle. It is primarily vegetative development before onset of flowering that is shortened by planting delays. Planting until the beginning of flowering is typically 45 to 60 days for full-season varieties planted at the normal time. This interval is shortened as planting is delayed; it may be only about 25 days when such varieties are planted in late June or early July. A rule of thumb is that for each 2- to 3-day delay in planting, maturation of the plant is delayed by one day. The lengths of the flowering period and of pod-filling also are shortened, but the effect of planting delays on these phases of development is minor.

Soybeans are photoperiod sensitive, meaning that the lengths of day and of night strongly influence when the plant initiates flowering. When planting is delayed, the day length to which soybean seedlings are exposed differs from that experienced with timely seeding in May. The response to photoperiod is the primary factor to which the crop responds, with the plant ultimately devoting fewer days to vegetative development before flowering begins. Warm temperatures at night also accelerate the onset of flowering. Figure 3.01 presents data collected over many years and many locations in Illinois, illustrating that delayed planting shortens the days required for soybeans to mature.

As stated previously, soybeans yield best when planted in May. Some growers have questioned whether planting before May would benefit the crop. Experience at research fields in Illinois and other midwestern states suggests that planting before May frequently puts the crop at risk due to soil conditions that are too cold and wet, as well as possibly exposing early emerged soybeans to a frost or freeze. Low temperatures inhibit germination, while cold and wet conditions favor disease on the seed or seedling. While planting in April occasionally works, it will neither work every year nor consistently yield the most



Dates are average planting and maturity dates compiled from USDA Uniform Soybean Tests Northern States, 1980–1993.

Figure 3.01. Planting date effect on maturity of soybeans with Group II, III, and IV maturities.

productive crop. Figure 3.02 summarizes the results of various planting dates for soybean at DeKalb and Monmouth and indicates no advantage in planting before late April or early May.

When spring conditions do not allow timely planting of soybean in May, the planting date may extend well into June, or in some cases early July. Such delays in planting have serious consequences to yield potential. The 1995 and 1996 weather patterns created problems with timely planting of soybean in Illinois. Delays into June tend to result in a shorter soybean plant with considerably fewer leaves, thus reducing the yield potential per plant. It is possible to offset somewhat the disadvantageous changes in plant morphology that lengthy delays cause by planting late-seeded soybeans in narrow rows and at a density higher than is used for timely May seeding.

Research in recent years on the best management for late-planted soybeans is limited; however, pioneering research at Dixon Springs on double-crop soybean management indicated an advantage to narrowing rows and increasing plant density in such late-planted fields. Tables 3.01 and 3.02 illustrate these benefits to soybean yield.

Delays in planting into mid-June may not require increased plant densities equivalent to those used in double-cropped fields, but an increase in planting rate of 20 to 30 percent should be advantageous. Soybeans planted during the end of June can also be expected to benefit from increased plant density similar to the double-crop results reported in Table 3.01. Combined with narrowed row spacing, increased plant density will benefit soybean yield when the crop is planted well past the most desirable planting date.

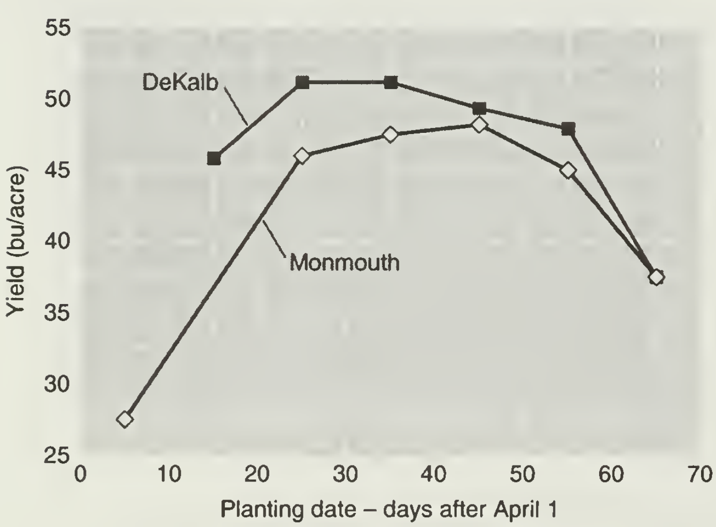


Figure 3.02. Seeding date effect on soybean yield, Monmouth and DeKalb.

Table 3.01. Double-Cropped Soybean Response to Increased Plant Densities

Plant density (thousands/A)	Yield (bu/A)
87	38
135	43
200	47
244	52
289	56

Table 3.02. Double-Cropped Soybean Response to Narrowed-Row Spacing

	30" spacing	20" spacing
Experiment 1	35.9	44.5
Experiment 2	32.7	41.6
Average	34.3	43.0

Planting Rate

Maximum yield from May-planted soybeans generally results from planting sufficient seed to establish 6 to 9 plants per foot of row in 30-inch rows, 5 to 6 plants per foot of row in 20-inch rows, and 3 to 4 plants per foot of row in 10-inch rows. Higher plant densities may be able to stand up with lodging-resistant varieties, but populations greater than 150,000 plants per acre are unlikely to consistently enhance yield. Excess plant densities require more seed to plant, which adds to production cost, and if weather happens to favor rank vegetative growth, varieties considered resistant to lodging can fall over.

An insufficient plant population will limit yield, as plants fail to form the complete canopy of leaves needed to fully use the available sunlight. It is particularly important to soybean yield that a complete canopy be in place by the time pods begin to form. Thin stands also allow more weed competition to develop in the crop and also encourage plants to branch and pod closer to the soil line, possibly adding to harvest losses.

Studies have demonstrated that the productive capacity of soybean is surprisingly good at rather low plant densities. At extremely low densities, a considerable amount of the production may not be efficiently harvested with a combine due to low podding and excessive branching low on the main stem of the plant. Precipitation and planting date actually determine what the "ideal" plant density may be in a given

year. In a dry year, when vegetative development of plants is restricted, higher densities of soybean are desirable so that a full canopy can develop. In contrast, a year with abundant rainfall following timely planting can result in excessive vegetative growth, possibly leading to lodging. At planting we cannot predict weather during vegetative growth, so a compromise in seeding rate offers the most yield potential.

Seeding-rate trials conducted in 30-inch row spacings suggest that a wide range of seeding rates will produce good yields. Seeding rates that result in approximately 150,000 plants per acre tend to produce best yields (Figure 3.03). Soybeans in narrow-row planting (drilled or otherwise) are often planted at a seeding rate resulting in densities greater than 150,000 plants per acre. If lodging-resistant varieties are planted, plant density can likely be increased to the range of 180,000 to 200,000 plants per acre without risk of lodging. Benefits to yield are often questionable, however, when plant densities exceed 150,000 plants per acre in a timely planted stand with uniform plant distribution.

The more rapid full canopy, which develops in fields planted to narrow rows at higher plant densities, has often been reported to aid in weed management through the shading imposed on weedy species. Shade pressure on weeds will help reduce weed growth but should not be relied upon solely as a means to suppress weedy competitors in narrow-row soybeans.

For seed of average size, planting 40 to 60 pounds per acre can achieve a stand of 110,000 to 150,000 plants per acre. Planting at rates toward the higher end of this range helps ensure a full stand; planting toward the low end might fail to produce adequate stands in an unfavorable environment, which limits emergence. It is generally wise to plant at a rate that achieves a stand toward the upper limit in plant density which the soybean variety will tolerate without lodging. Research on planting rates and yield potential indicates that virtually all varieties respond similarly to changes in seeding rate until the plant density reaches a level that results in lodging.

As previously mentioned, soybeans that are not timely planted in spring, and especially those planted after harvest of winter wheat, will have reduced vegetative development (fewer leaves per plant and a shorter stem) and will tend to be more resistant to lodging. Soybeans planted late or double-cropped need to be established at higher densities per acre and in narrow rows to allow the crop to fully intercept sunlight by the time pod development begins. Recommendations on planting rate therefore change as seeding is delayed from May to June or early July.

As row spacing narrows, fewer plants per foot of row are needed to achieve a given population of plants per acre (Table 3.03). The actual amount of seed needed per acre will be determined by the population density desired, seed size, and seed quality, as well as by field conditions and equipment considerations which relate to emergence of a viable seed. The extent to which seeds are dropped in excess of the desired plant density per acre depends on how probable it is for a viable seed to emerge. Seed drop rate per acre can be determined by the following calculation:

$$\frac{\text{desired stand/acre}}{\text{\% germination x \% survival of viable seed}}$$

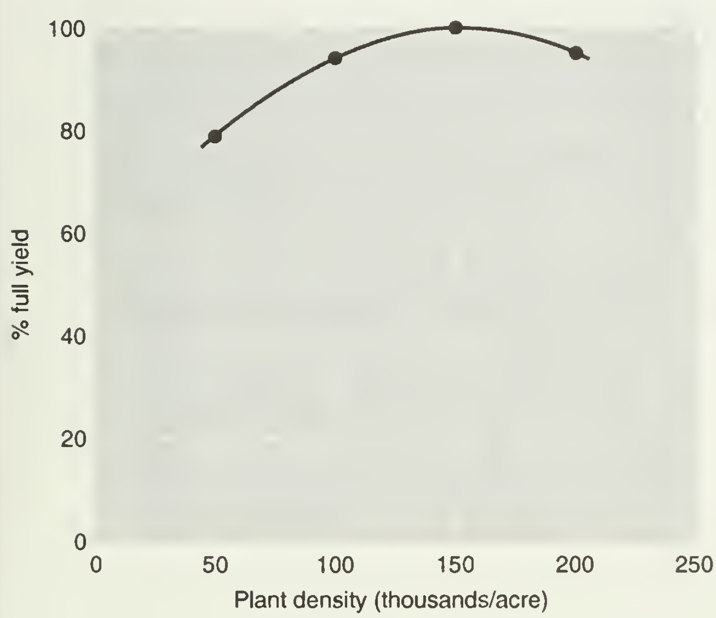


Figure 3.03. Effect of plant density on soybean yields.

Table 3.03. Soybean Plants Per Foot of Row for Different Populations in Various Row Spacings

Row spacing (in.)	Soybean population				
	125,000	150,000	175,000	200,000	225,000
	Average number of plants/foot of row required				
36"	8.6	10.3	12.0	13.8	15.5
30"	7.2	8.6	10.0	11.5	12.9
15"	3.6	4.3	5.0	5.7	6.5
10"	2.4	2.9	3.3	3.8	4.3
8"	1.9	2.3	2.7	3.1	3.4
7"	1.7	2.0	2.3	2.7	3.0

The germination for a seedlot can be taken from the seed tag, but the survival of viable seed is highly dependent on the environment and on placement by the planting equipment. Seedbed temperature and moisture level will determine how well germination can proceed. Planting equipment varies in the ability to maintain an appropriate depth of seed placement and uniformity of soil covering. The tillage system used will determine the crop residue remaining on the soil surface at planting, which in turn will influence seedbed moisture and temperature conditions at planting. The experience of the individual producer is needed to formulate a value for the survival of viable seed when planted in given fields. Once the seed drop rate per acre needed is known, the quantity of seed needed for planting can be determined (Table 3.04).

Planting Depth

Emergence will be more rapid and stands will be more uniform if soybeans are planted only 1½ to 2 inches deep. Deeper planting often results in lower emergence and poor stands.

Varieties differ in their ability to emerge when planted more than 2 inches deep. The description of a variety may mention an "emergence score," which reflects the ability of the seedling hypocotyl to elongate sufficiently when planting is deeper than recommended. Scores for emergence are usually given on a 1-to-5 scale, with a score of 1 indicating that the likelihood of emergence is very good and a score of 5 indicating that such probability is very weak. Special attention should be given to the planting depth of varieties that are known to have weaker emergence potentials. Because a variety has a tendency to emerge slowly or weakly from excessively deep planting does not mean it lacks the ability to produce a good crop when planted at a reasonable depth. It simply means that extra attention to depth of planting is needed to ensure a good stand.

Table 3.04. Soybean Seeding Requirements for Different Seed Sizes and Seed Drop Rates

Seed per lb	Lb of seed required for desired seed drop/acre			
	150,000	175,000	200,000	225,000
1,800	83	97	111	125
2,000	75	88	100	113
2,200	68	80	91	102
2,400	63	73	83	94
2,600	58	67	77	87
2,800	54	63	71	80
3,000	50	58	67	75
3,200	46	54	63	70

Crop Rotation

The crop preceding soybeans has an influence on yield potential. If soybeans are planted after soybeans, diseases and other pest problems may be intensified in the second and later years of production. Difficult-to-control weed problems will become worse. Research evidence also suggests that growth-inhibiting substances (allelopathic chemicals) are released from soybean residue as it decomposes in the soil. These substances have a negative effect on the growth and production of soybeans. To avoid this problem, sufficient time must elapse between one soybean crop and the next to allow decomposition of the soybean crop residue. Planting soybeans after soybeans will not provide a sufficient interval.

Several studies on the rotation benefits for soybean yield have been done. Table 3.05 summarizes these results, which indicate that higher yields tend to result from soybeans grown in rotation, compared to those from soybeans after soybeans.

Row Width

If weeds are controlled, soybeans often will yield more in narrow rows than in traditional row spacings of at least 30 inches. The yield advantage for narrow rows is usually greatest for earlier-maturing varieties, with full-season varieties showing smaller gains in yield as row spacing is reduced to less than 30 inches. Numerous studies have evaluated yield benefits associated with narrow rows in spring-planted soybeans, and their results are variable. Enhanced yield can be as much as 15 or 20 percent in some situations, while in others no enhanced yield is obtained. The advan-

Table 3.05. Effect of Crop Rotation on Soybean Yields

Location	Soybeans after	
	Soybeans	Corn
	Bushels per acre	
DeKalb	39	44
Dixon	30	35
Urbana	44	50
Brownstown	30	35

tage to yield realized in rows less than 30 inches will be determined by how well spacings of 30 inches or more can intercept light by the time reproductive growth on the plant begins. To predict whether narrowed rows will benefit yield, follow this rule of thumb: If a full canopy of leaves is not developed over the soil by the time pod development begins, then narrower row spacings can likely be advantageous to yield.

The relative maturity of the variety produced, growing conditions during the vegetative period of plant development, and planting date all influence the extent of canopy development by the time podding begins. Varieties that mature relatively early generally have the smallest canopies when podding begins and consequently can benefit most from narrow-row spacings. Dry or otherwise undesirable weather early in the season will reduce the amount of canopy developed before the onset of podding. When such weather patterns occur, rows that are narrower help develop a full canopy by the time podding begins. Delays in planting reduce the amount of canopy that develops before seed formation activity begins; thus when planting is delayed considerably, soybeans respond to narrower rows with yield increases. Double-crop soybeans planted after the small-grain harvest should be planted with a grain drill.

Interest in planting soybeans with a grain drill or other narrow-row equipment has grown considerably in recent years. A 1996 survey reported that average soybean row space was down to only 16 inches in Illinois. Advances in postemergence herbicides as well as available planting equipment have allowed growers to reduce row spacings in soybeans.

With spring planting in Illinois, it appears that row spacings in the range of 15 to 20 inches are generally adequate to facilitate full-canopy development by the time pod development begins on the crop, allowing narrow-row benefits to yield to be fully realized. Research has generally failed to demonstrate an advantage for drilled spacings compared to 15 to 20 inches when timely spring planting. This indicates that using rows spaced at 7 to 10 inches (drilled planting) is not required to gain the full benefits to yield associated with narrowed rows in Illinois. Several narrow-row planters have become available in recent years, indicating that the equipment industry is responding to the research-documented benefits of rows spaced 15 to 20 inches.

Double-Cropping Considerations

Double-cropped soybeans (planted following harvest of winter wheat in late June or early July) can be successfully produced most years in central and southern parts of Illinois. In some years the practice works in northern portions of the state as well, but in others the onset of cold weather will take a major toll on yield and quality of the crop produced.

Vegetative development on the double-cropped soybean plant is profoundly influenced by the late June or early July planting date. The environment into which double-crop soybeans emerge can be too dry for good emergence, and higher temperatures speed along the onset of flowering. An exceptionally early frost in the fall can damage the crop, which needs all of the average growing season to reach maturity. Yield potential of soybeans double-cropped is typically 50 or 60 percent of that obtained with timely planting in the first half of May.

The typical double-cropped soybean plant has a much shorter stem and fewer leaves than one timely planted in the first half of May. Shorter stems provide fewer potential places for pod formation. Higher populations of plants per acre are needed to allow the plant to intercept sunlight and maximize its yield potential. The smaller leaf area per plant creates a plant that responds favorably to narrow-row spacings. While the number of plants per acre established in double-crop tends to be much higher than with May planting, the short stature of the plant reduces greatly the chance of lodging problems.

Research on double-crop management across the Midwest suggests that planting with a grain drill is essential to obtain the full yield potential of double-crop soybeans. Small-statured plants are more responsive to narrow-row planting than plants resulting from May seeding. Increasing plant densities by 50 to 100 percent over that used with timely spring seeding has been found to benefit yield. Greater numbers of smaller-statured plants are required to capture sunlight effectively. Because July and August often are hot with limited rainfall, planting double-crop soybeans with a no-till drill is a practical means of conserving soil moisture, which is often in short supply following planting.

The double-crop soybean will germinate in a much warmer environment than do May-planted soybeans, which will allow for rapid emergence if moisture is available. Higher temperatures, though, especially at night, will limit vegetative development before flowering begins. The time devoted to vegetative development is abbreviated much more than is the interval devoted to podding and seed fill.

Varieties that tend to produce best double-crop yields are those which are classified as mid-season to full-season for the area. If a variety that is early for a location is planted, vegetative development prior to flowering is extremely limited. Those varieties with

determinate growth habit *should not be planted* for double-crop production. The stem terminates growth when flowering begins in determinate varieties, and because flowering occurs shortly after emergence on double-cropped soybeans, a determinate variety would produce an extremely short plant with low yield.

Based on research experiences across the Midwest, a recipe for successful double-crop soybeans needs to include narrow-row spacings, high plant densities per acre, varieties classified as mid-season to full-season for the area, management that helps conserve soil moisture, and a first fall frost that is no earlier than average.

When to Replant

Uniform full stands have been compared to those with irregular deficiencies of varying magnitudes to evaluate yield potentials of stands that are less than perfect (Tables 3.06 and 3.07). Studies strongly suggest that the soybean stand has a tremendous ability to compensate for missing plants. Because existing plants will develop more branches and pod more heavily, the effect of missing plants in the stand is often not detected in yields. The yield reduction associated with very poor stands may still be more profitable to the grower than a replanted field, which has additional costs associated with replanting and a reduced yield potential because of a delayed seeding date.

Data in Table 3.06 illustrate the soybean's ability to compensate for missing plants when randomly placed gaps occur in the stand. The influence of plant density in the remaining row sections is also apparent. For soybeans to exhibit their full capacity to compensate for missing plants, it is necessary to control weed growth in the areas without soybean plants. In a field situation where poor stands are realized, management to control weeds is essential to prevent further yield losses due to the poor stand. Maintaining the necessary weed control must be considered a cost of keeping a less-than-perfect stand.

Growers who replant do so at a later planting date than is best. A penalty to yield due to delayed planting of 2 to 3 weeks is reflected in values presented in Table 3.07. The plant density per foot of row achieved with replanting, along with possible gaps in that stand, will also influence yield potential. It is wise to remember that replanted soybeans are not guaranteed to grow: A perfect stand is not always achieved when a poor stand is destroyed and the field is replanted.

At a given level of stand reduction, the impact on yield is minimized if the gaps are small rather than large. A gap of 16 inches has been found to have no influence on yield of soybeans grown in 30-inch row spacing, provided adjacent rows have a full stand. Compensation for gaps in the row occurs not only in the row where the gap is located but also in the rows bordering the gap. The degree of compensation exhibited by soybeans should be enhanced as rows are spaced closer together. Under such planting arrangements, the plants are initially more uniformly spaced

Table 3.06. Percent of Full-Yield Potential for Timely Planted Soybeans, as Influenced by Plant Density Established and Stand Reduction

	Plants per foot of row[b]		
Stand reduction[a]	8	6	4
	Percent of full-yield potential		
0 (full stand)	100	97	95
10 percent	98	96	93
20 percent	96	93	91
30 percent	93	90	88
40 percent	89	86	83
50 percent	84	81	78
60 percent	78	75	73

[a]Reduction in stand achieved by random placement gaps 12 inches long.
[b]Plants per foot of row in row sections with no gaps or skips.

Table 3.07. Percent of Full Yield Expected from Replanting Soybeans, as Influenced by Plants Per Foot of Row and Stand Deficiency

	Plants per foot of row[b]		
Stand-deficiency level[a]	8	6	4
	Percent of full-yield potential		
0 (full stand)	89	86	83
10 percent	88	85	83
20 percent	86	84	81
30 percent	84	81	79
40 percent	81	78	75
50 percent	76	74	71
60 percent	71	69	66

[a]Reduction in stand achieved by random placement gaps 12 inches long.
[b]Plants per foot of row in row sections with no gaps or skips.

Table 3.08. Quality Differences in Soybeans from Different Sources

Source	Germination (%)	Pure seed (%)	Inert matter (%)	Seed cleaned (%)	Seed germination tested (%)
1985 survey					
Certified seed	88.2	99.5	0.42	100	100
Bin-run seed	85.9	98.1	1.19	51	14
1986 survey					
Certified seed	89.0	99.4	0.29	100	100
Bin-run seed	87.7	98.6	1.59	90	10

in the field, making it more likely they can fully compensate for a stand deficiency of a given level. Extension Circular 1317, *Managing Deficient Soybean Stands*, can be useful to growers making a replanting decision.

Seed Source

To ensure a good crop, you must select high-quality seed. When evaluating seed quality, consider the percent germination, percent pure seed, percent inert matter, percent weed seed, and the presence of diseased and damaged seed.

Samples of soybean seed taken from the planter box as farmers were planting showed that homegrown seed was inferior to seed from other sources (Table 3.08). The number of seeds that germinate and the pure seed content of homegrown seeds were lower. Weed seed content, percent inert material (hulls, straw, dirt, and stones), and presence of other crop seeds (particularly corn) were higher in homegrown seed.

This evidence indicates that the Illinois farmer can improve soybean production potential by using higher quality seed. Homegrown seed is the basic problem. Few producers are equipped to carefully harvest, dry, store, and clean seeds and to perform laboratory tests that adequately assure high quality. A grower who is not a professional seed producer and processor may be well advised to market the homegrown soybeans and obtain high-quality seed from a reputable professional dealer.

A state tag is attached to each legal sale from a seed dealer. Read the analysis and evaluate if the seed being purchased has the desired germination, purity, and freedom from weeds, inert material, and other crop seeds. The certification tag verifies that an unbiased nonprofit organization (in our state, the Illinois Crop Improvement Association) has inspected the production field and the processing plant. These inspections certify that the seeds are of a particular variety as named and have met certain minimum quality standards. Because some seed dealers may have higher quality seed than others, it always pays to read the tag.

Seed Size

The issue of how the size of seed planted affects soybean growth and the final yield often arises following a year with stress during the seed-fill period, which reduces final seed size. Research suggests little detrimental effect from planting seed smaller than normal.

Across a broad range of seed sizes, insignificant effects on emergence have been reported. Seeds of extremely small size, which normally do not make their way into the market, may be reduced in emergence when planted at a normal depth of 1 to 2 inches.

Final differences in plant size, which might result from planting seeds of different sizes, do not suggest any problems with using small seed. Any differences reported on final plant size are so small (less than 4 inches) that they would likely not have a significant effect on yield.

The size of seed produced by soybeans is determined by a combination of genetic factors for the variety and the environment in which the seeds develop. Whether soybeans are large or small, seed for a given variety has the same genetic potential. The size of the seed produced on a plant established by planting a small seed is thus expected to be the same as the size of the seed from a plant grown from large seed.

Effects of seed size on final yield, which is the ultimate concern of growers, appears to be minimal. When you shop for soybean seed, seed quality should be a more important consideration than size. If smaller-than-normal seed will be used to establish soybeans, check your planter calibration to meter the seed at the proper rate. Excessive seeding rates, resulting from misadjusted planting equipment metering small seed, can result in excessively thick stands that will be more prone to lodging.

Varieties

Soybean varieties are divided into groups according to their relative times of maturity (see Table 3.09). Varieties of Maturity Group I are nearly full season in northernmost Illinois but are too early for good growth and yield farther south. In extreme southern Illinois, varieties in Maturity Groups IV and V are best adapted.

Table 3.09. Characteristics of Public Soybean Varieties

Variety	Relative maturity (days)	Lodging score[a] (1–5 scale)	Soybean cyst resistance[b] (races) 1	2	3	4	5	14	Phytophthora resistance[b] Races 1, 2	Races 4, 5	Races 3, 6–9	Seed protein[c] (%)	Seed oil[c] (%)
Group I													
IA1006	–11	2.2	S	S	S	S	S	S	R	S	S	34.1	19.2
Group II													
Burlison	–3	1.9	S	S	S	S	S	S	R	R	R	38.3	17.5
Dwight*	0	1.5	S	MR	R	R	MR	R	S	S	S	35.8	18.4
IA2036*	–3	2.8	S	R	R	R	MS	R	S	S	S	36.0	17.3
Jack	3	2.9	S	R	R	R	MS	R	S	S	S	35.5	18.4
Savoy	–3	1.3	S	S	S	S	S	S	R	R	R	37.3	18.2
Group III													
Edison	–2	1.8	S	S	S	S	S	S	R	R	R	36.2	18.8
IA3005	–1	2.1	S	R	R	R	—	R	R	S	S	34.7	19.3
Iroquois	–3	2.0	S	S	S	S	S	S	R	S	S	35.2	19.3
Linford	1	2.1	S	R	R	R	—	R	S	S	S	36.5	18.9
Macon	2	1.9	S	S	S	S	S	S	S	S	S	34.8	19.2
Maverick	4	2.8	S	R	R	R	—	R	R	R	R	34.8	18.8
Pana*	3	2.8	S	R	R	R	MR	R	S	S	S	33.3	19.5
Probst	–1	2.1	S	S	S	S	S	S	R	R	R	35.5	19.2
Resnik	9/21	1.5	S	S	S	S	S	S	R	R	R	35.4	18.7
Saline	4	2.5	S	—	R	MR	—	R	S	S	S	34.1	20.2
Thorned	0	1.9	S	S	S	S	S	S	R	R	R	35.7	19.4
Yale	3	2.0	S	—	R	R	—	R	S	S	S	35.4	19.8
Group IV													
Bronson	5	2.7	S	—	R	R	—	R	R	S	S	36.4	18.7
Flyer	4	1.8	S	S	S	S	S	S	R	R	R	36.3	18.8
Ina**	9	3.0	R	MR	R	MS	R	R	S	S	S	33.9	18.7
Omaha	5	1.7	S	S	S	S	S	S	R	R	R	36.2	19.8
Rend**	5	2.6	S	R	R	R	R	R	S	S	S	36.5	18.3

NOTE: Height and lodging score comparisons should be made within maturity groups.
*Available to farmers in 1999.
**Available to farmers in 2000.
[a]1 = all plants standing, 5 = all plants flat.
[b]R = resistant, MR = moderately resistant, S = susceptible.
[c]Protein and oil values based on 13% moisture content, 1995–96 average.
[d]Variety is resistant to brown stem rot.

Traditionally, soybeans grown in the Midwest have had indeterminate growth habits; that is, vegetative growth continues beyond the time when flowering begins, continuing generally until seed filling begins. In the late 1970s and early 1980s a few short-statured determinate varieties having maturities appropriate to Illinois were released. The primary advantage of such varieties was excellent resistance to lodging in a high-yield environment. The determinate growth-habit trait terminates vegetative development on the main stem when flowering begins. While reduced main stem length reduces lodging potential, determinate varieties require above-average growing conditions prior to flower in order to consistently offer a yield advantage. Stress early in the season or delayed planting date can severely limit yield of determinate varieties in the Midwest because inadequate vegetative development prior to flower results. There are currently a very limited number of soybean acres planted to determinate varieties in Illinois.

Literally hundreds of soybeans are available for the producer's consideration, with most varieties offered by private seed companies. Varieties from private companies now occupy most soybean fields in Illinois, with the remainder of acres planted to public varieties (released by universities or USDA). Soybeans from public sources are elaborated in Table 3.09, which summarizes many agronomic characters, disease reactions, and other traits of the major and newer public soybeans being used currently in Illinois.

Most soybean acres in Illinois are planted from Maturity Group II, III, or IV. A few Group I and Group V varieties are grown in the northern and southern extremes of the state, respectively. For specific performance data on both public and private varieties, consult the latest issue of *Performance of Commercial Soybeans in Illinois* from the Soybean Variety Testing Project.

Regardless of the soybean variety a producer chooses to plant, considering the overall advantages of the options available is important. When choosing a variety, first consider a suitable maturity coupled with a good yield-to-performance record. Further refine the selection process by considering the variety's genetic resistance to prevalent pest problems. If you are producing for niche-market contracts, your choices will be relatively limited and may not include the best-yielding or most pest-resistant varieties. If current trends in variety development continue, one can anticipate that consideration of herbicide tolerance or resistance may be included in the variety selection process.

AUTHOR

Gary E. Pepper
Department of Crop Sciences

Chapter 4. Small Grains

Winter Wheat

Although both soft red and hard red winter wheat can be grown in Illinois, improved soft wheat varieties are widely adapted in the state; nearly all of Illinois wheat is the soft type. The primary reasons for this are the better yields of soft wheat and the sometimes poor bread-making quality of hard wheat produced in our warm and humid climate. Because it may be difficult to find a market for hard wheat in many parts of the state, it is advisable to line up a market before planting the crop.

Wheat in the Cropping System

In recent years, wheat acreage in Illinois has averaged about 1.4 million acres planted, with an average of about 1.2 million acres harvested. Most of the wheat acreage is in the southern half of the state, and a majority of the acreage south of I-70 is double-cropped with soybeans each year. Much of the crop in the northern part of the state is planted by livestock producers, who often value the straw as much as the grain, and who often spread manure on the fields after wheat harvest. For those considering producing wheat, these points may help in making the decision:

1. State average yields have ranged from 32 to 59 bushels per acre over the past 15 years, with county average yields often correlated with average corn yields. Under very favorable spring weather conditions (i.e., dry weather in May and June), yields on some farms have exceeded 100 bushels per acre. As a rule of thumb, wheat yields average about one-third those of corn, but they are about one-half those of corn when weather is favorable for both crops. Having different weather requirements from corn and soybeans, wheat helps spread weather risks.
2. Wheat costs less to produce than corn, but gross and net incomes from wheat are likely to be less than for corn or soybeans. Added income from double-crop soybeans or from straw, however, improves the economic return from wheat. Wheat also provides income in midsummer, several months before corn and soybean income.
3. Wheat is one of the best annual crops in Illinois for erosion control, because it is in the field for some 8½ to 9 months of the year and is well established during heavy spring rainfall. Wheat can also serve to break crop rotations that would otherwise lead to buildups in diseases or insects.
4. Wheat crop abandonment is higher than for other crops, but wheat acres not harvested can be planted to spring-seeded crops, usually at their optimum planting times.

Dates of Seeding

The Hessian fly–free dates for each county in Illinois are given in Table 4.01. Wheat planted on or after the fly-free date is much less likely to be damaged by the insect than wheat planted earlier. It also will be less severely damaged in the fall by diseases such as Septoria leaf spot, which is favored by the excessive fall growth usually associated with early planting. Because the aphids that carry the barley yellow dwarf (BYD) virus and the mites that carry the wheat streak mosaic virus are killed by freezing temperatures, the effects of these viruses will be less severe if wheat is planted shortly before the first killing freeze. Finally, wheat planted on or after the fly-free date will probably suffer less from soil-borne mosaic; most varieties of soft red winter wheat carry resistance to this disease, but some show symptoms if severely infested.

The decreases in yield as planting is delayed past the fly-free date vary considerably, depending on the year and the location within Illinois. In general, studies have shown that yields decline little with planting delays for the first 10 days after the fly-free date. From 10 to 20 days late, yields decline at the rate of a

Table 4.01. Hessian Fly–Free Dates for Seeding Wheat

County	Average date of seeding wheat for highest yield	County	Average date of seeding wheat for highest yield	County	Average date of seeding wheat for highest yield	County	Average date of seeding wheat for highest yield
Adams	Sept. 30–Oct. 3	Ford	Sept. 23–29	Livingston	Sept. 23–25	Randolph	Oct. 9–11
Alexander	Oct. 12	Franklin	Oct. 10–12	Logan	Sept. 29–Oct. 3	Richland	Oct. 8–10
Bond	Oct. 7–9	Fulton	Sept. 27–30	Macon	Oct. 1–3	Rock Island	Sept. 20–22
Boone	Sept. 17–19	Gallatin	Oct. 11–12	Macoupin	Oct. 4–7	St. Clair	Oct. 9–11
Brown	Sept. 30–Oct. 2	Greene	Oct. 4–7	Madison	Oct. 7–9	Saline	Oct. 11–12
Bureau	Sept. 21–24	Grundy	Sept. 22–24	Marion	Oct. 8–10	Sangamon	Oct. 1–5
Calhoun	Oct. 4–8	Hamilton	Oct. 10–11	Marshall-Putnam	Sept. 23–26	Schuyler	Sept. 29–Oct. 1
Carroll	Sept. 19–21	Hancock	Sept. 27–30			Scott	Oct. 2–4
Cass	Sept. 30–Oct. 2	Hardin	Oct. 11–12	Mason	Sept. 29–Oct. 1	Shelby	Oct. 3–5
Champaign	Sept. 29–Oct. 2	Henderson	Sept. 23–28	Massac	Oct. 11–12	Stark	Sept. 23–25
Christian	Oct. 2–4	Henry	Sept. 21–23	McDonough	Sept. 29–Oct. 1	Stephenson	Sept. 17–20
Clark	Oct. 4–6	Iroquois	Sept. 24–29	McHenry	Sept. 17–20	Tazewell	Sept. 27–Oct. 1
Clay	Oct. 7–10	Jackson	Oct. 11–12	McLean	Sept. 27–Oct. 1	Union	Oct. 11–12
Clinton	Oct. 8–10	Jasper	Oct. 6–8	Menard	Sept. 30–Oct. 2	Vermilion	Sept. 28–Oct. 2
Coles	Oct. 3–5	Jefferson	Oct. 9–11	Mercer	Sept. 22–25	Wabash	Oct. 9–11
Cook	Sept. 19–22	Jersey	Oct. 6–8	Monroe	Oct. 9–11	Warren	Sept. 23–27
Crawford	Oct. 6–8	Jo Daviess	Sept. 17–20	Montgomery	Oct. 4–7	Washington	Oct. 9–11
Cumberland	Oct. 4–5	Johnson	Oct. 10–12	Morgan	Oct. 2–4	Wayne	Oct. 9–11
DeKalb	Sept. 19–21	Kane	Sept. 19–21	Moultrie	Oct. 2–4	White	Oct. 9–11
DeWitt	Sept. 29–Oct. 1	Kankakee	Sept. 22–25	Ogle	Sept. 19–21	Whiteside	Sept. 20–22
Douglas	Oct. 2–3	Kendall	Sept. 20–22	Peoria	Sept. 23–28	Will	Sept. 21–24
DuPage	Sept. 19–21	Knox	Sept. 23–27	Perry	Oct. 10–11	Williamson	Oct. 11–12
Edgar	Oct. 2–4	Lake	Sept. 17–20	Piatt	Sept. 29–Oct. 2	Winnebago	Sept. 17–20
Edwards	Oct. 9–10	LaSalle	Sept. 19–24	Pike	Oct. 2–4	Woodford	Sept. 26–28
Effingham	Oct. 5–8	Lawrence	Oct. 8–10	Pope	Oct. 11–12		
Fayette	Oct. 4–8	Lee	Sept. 19–21	Pulaski	Oct. 11–12		

bushel or so per day. This yield loss accelerates to as much as 2 bushels per day from 20 to 30 days late, with sharper declines in the northern part of the state. By one month after the fly-free date, yield potential is probably only 60 to 70 percent of normal, making this about the latest practical date to plant wheat. Wheat may survive even if planted so late that it fails to emerge in the fall, but reduced tillering and marginal winterhardiness often results in large yield decreases.

The planting date has a major effect on the winter survivability of the wheat plant. It is best if the plant can grow to about the 3-leaf stage, usually forming a tiller or two. By the time the plant reaches this growth stage, it has stored some sugars in the crown (lower stem) of the plant. These sugars act as antifreeze, allowing the crown and new buds to survive soil temperatures down to 15°F or so. Late-planted wheat does not have time to produce and store such sugars before soils freeze, while early planting tends to result in rapid plant growth with less storage of sugars. Freeze-thaw cycles during the winter tend to use up stored sugars, thereby decreasing winterhardiness. Varieties also differ in their ability to survive low temperatures, but many of the higher-yielding varieties begin growth early in the spring, and this trait tends to be associated with less winterhardiness.

Rates of Seeding

While seeding rate recommendations for wheat have usually been expressed as pounds of seed per acre, differences in seed size can mean that the number of seeds per acre or per square foot may not be very precisely specified. Research in Illinois has measured yields in response to varying the number of seeds from 24 to 48 per square foot. Results given in Table 4.02 indicate that seed rates within this range affect yields very little, though in northern Illinois, where there was some cold injury in the spring, the

Table 4.02. Effect of Seed Rates on Wheat Yield

Seeds per square foot	Wheat yield (bu/A) Southern Illinois[a]	Northern Illinois[b]
24	77.2	71.8
36	77.6	74.0
48	77.8	75.9

[a]Average of four trials conducted at Belleville and Brownstown.
[b]Average of four trials conducted at Urbana and DeKalb.

Table 4.03. Conversion Chart for Number of Wheat Seeds or Plants Per Square Foot, Per Acre, and Per Linear Foot of Drilled Row

Seeds or plants per square foot	Seeds or plants per acre (millions)	Seeds or plants per foot of row at row spacing of: 6 in.	7 in.	8 in.	10 in.
20	0.87	10	12	13	17
24	1.05	12	14	16	20
28	1.22	14	16	19	23
32	1.39	16	19	21	27
36	1.57	18	21	24	30
40	1.74	20	23	27	33

Table 4.04. Conversion Chart for Pounds of Wheat Seeds of Different Sizes Needed Per Square Foot and Per Acre

Seeds per square foot	Seeds per acre (millions)	Lb of seed needed per acre when seed size (in seeds per pound) is: 11,000	13,000	15,000	17,000
24	1.05	95	80	70	61
28	1.22	111	94	81	72
32	1.39	127	107	93	82
36	1.57	143	121	105	92
40	1.74	158	134	116	102

extra plants gave a slight yield advantage. On average, though, it appears that a seeding rate of about 30 to 35 seeds per square foot is adequate for top yields when planting is done on time.

Seed size in wheat varies by variety and by weather during seed production but usually ranges from 11,000 to 17,000 seeds per pound. Table 4.03 converts seed rates per square foot to those per acre and per linear foot. These numbers are useful for calibrating a drill. Some seed bags list the number of seeds per pound. If not, a simple estimate may be needed. Large seed has 11,000 to 13,000 per pound; medium 14,000 to 16,000 per pound; and small 17,000 to 18,000 per pound. Table 4.04 gives the pounds of seed per acre needed for various seed sizes. A stand of 25 to 30 plants per square foot is generally considered the optimum, and a minimum of 15 to 20 plants per square foot is needed to justify keeping a field in the spring.

If planting is delayed much past the fly-free date, then fall growth and spring tillering are likely to be reduced. To compensate, the seeding rate should be increased by 10 percent for each week of delay in planting after the fly-free date.

Seed Treatment

Treating wheat seeds with the proper fungicide or mixture of fungicides is an inexpensive way to help ensure improved stands and better seed quality. Under conditions that favor the development of seedling diseases, the yield from treated seed may be 3 to 5 bushels higher than that from untreated seed. See Chapter 18, "Disease Management for Field Crops," for more information.

Seedbed Preparation

Wheat requires good seed-soil contact and moderate soil moisture for germination and emergence. Generally, one or two trips with a disk harrow or field cultivator will produce an adequate seedbed if the soil is not too wet. It is better to wait until the soil dries sufficiently before preparing it for wheat, even if planting is delayed.

No-Tilling

While some producers prefer to do some tillage to improve seed-soil contact for wheat, others have had good success drilling wheat without tillage. This approach requires adequate weight and covering mechanisms on the drill. Other considerations for no-tilling wheat include these:

1. Residue from the previous crop must be spread uniformly to prevent seed placement problems.
2. Without tillage to destroy emerging weeds, herbicides may need to be considered in the fall.
3. Seed rates should be equal to or slightly higher than those used for tilled fields.

4. Corn residue should be allowed to dry in the morning before drilling to prevent its being pushed down into the seed furrow.

There has also been concern about residue from the previous crop providing a place for diseases (such as head scab) to build up. While this may well be a factor, fields that are tilled also have suffered heavy damage when conditions are favorable for disease development; tillage is not the deciding factor in most cases. Wet soils and compaction from harvest equipment have also been found to reduce no-till stands more than when soils are tilled.

Depth of Seeding

Wheat should not be planted deeper than 1 to 1½ inches. Deeper planting may result in poor emergence. Drilling is the best way to ensure proper depth of placement.

Though a drill is best for placing seed at the right depth, a number of growers use fertilizer spreaders to seed wheat. This practice is somewhat risky but often works well, especially if rain falls after planting. An air-flow fertilizer spreader usually gives a better distribution than a spinner type. If seed is broadcast, the seeding rate should be increased by 20 to 30 percent to compensate for uneven placement. After broadcast seeding, the field may be rolled with a cultipacker or cultimulcher (with the tines set shallow), or it may be tilled very lightly with a disk or tine harrow to improve seed-soil contact.

Row Spacing

Research on row spacing generally shows little advantage for planting wheat in rows that are less than 7 or 8 inches apart. Yield is usually reduced by wider rows, with a reduction of about 1 to 2 bushels in 10-inch rows. Wisconsin data show greater yield reductions in 10-inch rows, probably due to slower early growth than is common in Illinois.

Varieties

The genetic improvement of wheat has continued with the involvement of both the private sector and public institutions. As a result, there are now some 50 varieties sold in Illinois, with more than half provided by private companies.

Both public and private varieties are tested at six locations in Illinois each year, and the results are assembled in a report titled *Wheat Performance in Illinois Trials*. The report also describes varieties, including both agronomic characteristics and resistance to diseases. Copies of this report are available in Extension offices by mid-August to allow use of the information before planting.

Intensive Management

Close examination of the methods used to produce very high wheat yields in Europe has increased interest in application of similar "intensive" management practices in the United States. Such practices generally include narrow row spacing (4 to 5 inches); high seeding rates (3 to 4 bushels per acre); high nitrogen rates, split into three or more applications; and heavy use of foliar fungicides for disease control and plant growth regulators to reduce height and lodging.

From research conducted in Illinois, it has become apparent that responses to these inputs are much less predictable in Illinois than in Europe, primarily because of the very different climatic conditions. Following is a summary of research findings to date:

1. Research in Indiana and other states shows that the response to rows narrower than 7 or 8 inches is quite erratic, with little evidence to suggest that the narrow rows will pay added equipment costs.
2. Seeding rates of 30 to 35 seeds per square foot generally produce maximum yields.
3. Increasing nitrogen beyond the recommended rates of 50 to 110 pounds per acre has not increased yields. Splitting spring nitrogen into two or more applications has not increased yields in most cases, but it may do so if very wet weather after nitrogen application results in loss of nitrogen.
4. Although foliar fungicides are useful if diseases are found, routine use has resulted in yield increases of only 3 to 5 bushels per acre (Table 4.05) and is probably not economically justified, unless disease levels are high.

Table 4.05. Response of Caldwell Wheat to Tilt Fungicide

	Yield (bu/A)	
Treatment	Southern Illinois[a]	Northern Illinois[b]
–Tilt	55.2	64.3
+Tilt	57.7	69.5

[a]Average of four trials at Brownstown and Belleville.
[b]Average of four trials at Urbana and DeKalb.

Wheat Management for Best Yields

Despite our best efforts at managing wheat, harsh winter weather or wet weather in May and June can spell disaster for the crop, and there may be little that can be done to maintain good yields. To help ensure good yields when the weather is favorable, follow these steps:

1. Choose several top varieties.
2. Apply some nitrogen and necessary phosphorus fertilizer before planting: 18-46-0 provides both nutrients.
3. Drill the seed on or near the fly-free date, using 30 to 35 seeds per square foot of good-quality seed.
4. Topdress additional nitrogen at the appropriate rate in late winter or early spring, at about the time that the crop breaks dormancy and begins to green up. Application to frozen soil is acceptable, but some nitrogen may run off if rain falls on sloping soil before it thaws.
5. Scout for weeds, insects, and diseases beginning in early April and treat for control only if necessary.
6. Hope for dry weather during and after heading.

Spring Wheat

Spring wheat is not well adapted to Illinois. Because it matures more than 2 weeks later than winter wheat, it is in the process of filling kernels during the hot weather typical of late June and the first half of July. Consequently, yields average only about 50 to 60 percent of those of winter wheat.

With the exception of planting time, production practices for spring wheat are similar to those for winter wheat. Because of the lower yield potential, nitrogen rates should be 20 to 30 pounds less than those for winter wheat. Spring wheat should be planted in early spring, as soon as a seedbed can be prepared. If planting is delayed beyond April 10, yields are likely to be very low, and another crop should be considered.

Very little spring wheat is grown in Illinois, and there has been little testing of spring wheat varieties. Most spring wheat varieties that may grow reasonably well in Illinois were bred in Minnesota or other northern states, and so there is a risk when they are grown here. Some of the varieties that have been tested in the past include Wheaton, Sharp, Grandin, Marshall, and Guard, all of which produced similar yields (around 40 bushels per acre) in Illinois trials. There are no clearly superior varieties for either yield or quality.

Rye

Both winter and spring varieties of rye are available, but only the winter type is suitable for use in Illinois. Winter rye is often used as a cover crop to prevent wind erosion of sandy soils. The crop is very winter-hardy, grows late into the fall, and is quite tolerant of drought. Rye generally matures 1 or 2 weeks before wheat. The major drawbacks to raising rye are the low yield potential and the very limited market for the crop. It is less desirable than other small grains as a feed grain.

The cultural practices for rye are similar to those for wheat. Planting can be somewhat earlier, and the nitrogen rate should be 20 to 30 pounds less than that for wheat because of lower yield potential. Watch for shattering as grain nears maturity. Watch also for the ergot fungus, which replaces grains in the head and is poisonous to livestock. Ergot may develop when weather is wet at heading.

There has been very little development of varieties specifically for the Corn Belt, and little yield testing has been done recently in Illinois. Much of the rye seed available in Illinois is simply called common rye; some of this probably descended from Balbo, a variety released in 1933 and widely grown many years ago in Illinois. More recently developed varieties that may do reasonably well in Illinois include **Hancock**, released by Wisconsin in 1979, and **Rymin**, released by Minnesota in 1973. **Spooner** is another Wisconsin variety that may be suitable.

Triticale

Triticale is a crop that resulted from the crossing of wheat and rye in the 1800s. The varieties currently available are not well adapted to Illinois and are usually deficient in some characteristic such as winterhardiness, seed set, or seed quality. In addition, they are of feed quality only. They do not possess the milling and baking qualities needed for use in human food.

Cultural practices for triticale are much the same as those for wheat and rye. The crop should be planted on time to help winter survival. As with rye, the nitrogen rate should be reduced to reflect the lower yield potential. With essentially no commercial market for triticale, growers should make certain they have a use for the crop before growing it. Generally when triticale is fed to livestock, it must be blended with other feed grains. Triticale is also used as a forage crop. The crop should be cut in the milk stage when it is harvested for forage.

A limited testing program at Urbana indicates that the crop is generally lower yielding than winter

wheat and spring oats. Both spring and winter types of triticale are available, but only the winter type is suitable for Illinois. Caution must be used in selecting a variety because most winter varieties available are adapted to the South and may not be winterhardy in Illinois. Yields of breeding lines tested at Urbana have generally ranged from 30 to 70 bushels per acre.

Spring Oats

To obtain high yields of spring oats, plant the crop as soon as you can prepare a seedbed. Yield reductions become quite severe if planting is delayed beyond April 1 in central Illinois and beyond April 15 in northern Illinois. After May 1, another crop should be considered unless the oats are being used as a companion crop for forage crop establishment and yield of the oats is not important.

When planting oats after corn, it will probably be desirable to disk the stalks; plowing may produce higher yields but is usually impractical. When planting oats after soybeans, disking is usually the only preparation needed, and it may be unnecessary if the soybean residue is evenly distributed. Make certain that the labels of the herbicides used on the previous crop allow oats to be planted; oats are quite sensitive to a number of common herbicides.

Before planting, treat the seed with a fungicide or a combination of fungicides. Seed treatment protects the seed during the germination process from seed- and soil-borne fungi. See Chapter 18, "Disease Management for Field Crops."

Oats may be broadcast and disked in but will yield 7 to 10 bushels more per acre if drilled. When drilling, plant at a rate of 2 to 3 bushels per acre. If the oats are broadcast and disked in, increase the rate by ½ to 1 bushel per acre.

For suggestions on fertilizing oats, see Chapter 11, "Soil Testing and Fertility."

Varieties

Illinois has for years been a leading state in the development of oat varieties. Excellent progress has been made in selecting varieties with high yield, good standability, and resistance to barley yellow dwarf mosaic virus (also called redleaf disease), which is the most serious disease of oats in Illinois.

Some of the newer spring oat varieties include Blaze, Brawn, Chaps, Don, Hazel, Ogle, and Rodeo, all developed in Illinois; Newdak from North Dakota, Prairie from Wisconsin, and Classic from Indiana. Yield and test weight data and descriptions of these varieties are published by the Illinois Crop Improvement Association in their annual *Oat Decision Maker*.

Winter Oats

Winter oats are not as winterhardy as wheat and are adapted to only the southern third or quarter of the state; U.S. Highway 50 is about the northern limit for winter oats. Because winter oats are somewhat winter-tender and are not attacked by Hessian fly, planting in early September is highly desirable. Experience has shown that oats planted before September 15 are more likely to survive the winter than those planted after September 15. Barley yellow dwarf virus may infect early-planted winter oats, however.

The same type of seedbed is needed for winter oats as for winter wheat. The fertility program should be similar to that for spring oats. Seeding rate is 2 to 3 bushels per acre when drilled.

Development of winter oat varieties has virtually stopped in the Midwest because of the frequent winter kill. Of the older varieties, **Norline**, **Compact**, and **Walken** are sufficiently winterhardy to survive some winters in the southern third of the state. All of these varieties were released more than 20 years ago. Walken has the best lodging resistance of the three.

Spring Barley

Spring barley is damaged by hot, dry weather and therefore is adapted only to the northern part of Illinois. Good yields are possible, especially if the crop is planted in March or early April, but yields tend to be erratic. Markets for malting barley are not established in Illinois, and malting quality may be a problem. Barley can, however, be fed to livestock.

Plant spring barley early—about the same time as spring oats. Drill 1 to 2 bushels of seed per acre. To avoid excessive lodging, harvest the crop as soon as it is ripe. Fertility requirements for spring barley are essentially the same as for spring oats.

The situation with spring barley varieties is similar to that for spring wheat: most varieties originate in Minnesota or North Dakota and have not been widely tested or grown for seed in Illinois. Some of these varieties are Azure, Hazen, Manker, Morex, Norbert, Robust, and Excel. Seed for any of these will likely need to be brought in from Minnesota or the Dakotas.

Winter Barley

Winter barley is not as winterhardy as the commonly grown varieties of winter wheat and should be planted 1 to 2 weeks earlier than winter wheat. Sow with a drill and plant 2 bushels of seed per acre.

The fertility requirements for winter barley are similar to those for winter wheat except that less

nitrogen is required. Most winter barley varieties are less resistant to lodging than are winter wheat varieties. Winter barley cannot stand "wet feet"; it should not be planted on land that tends to stay wet. The barley yellow dwarf virus is a serious threat to winter barley production.

Varieties

The acreage of winter barley is very small in Illinois, and variety testing has not been extensive. Based on limited testing, the varieties described here appear to have the best chance of producing a good crop under Illinois conditions. There has been little or no certified seed of these varieties produced in Illinois, but the higher yields may make it worthwhile to find seed in another state.

Pennco, released in 1985 by Pennsylvania, is a high-yielding variety with good disease resistance and standability. It is a few days earlier and slightly more winterhardy than Wysor and is considerably more winterhardy (though later in maturity) than **Barsoy**, an old variety that was once common in Illinois.

Wysor, released in 1985 by Virginia, is a high-yielding variety with good disease resistance and winterhardiness.

Author

Emerson D. Nafziger
Department of Crop Sciences

Chapter 5. Grain Sorghum

Although grain sorghum can be grown throughout Illinois, its greatest potential, in comparison with other crops, is in the southern third of the state. It is adapted to almost all soils, from sand to heavy clay. Its greatest advantage over corn is tolerance of moisture extremes. Grain sorghum usually yields more than corn when moisture is in short supply, but it often yields less than corn under better growing conditions. Grain sorghum is also less affected by late planting and high temperatures during the growing season, but the crop is very sensitive to cool weather and will be killed by even light frost.

Although few side-by-side comparisons of corn and grain sorghum in southern Illinois are available, some indication of relative yields is available from the hybrid trials that are conducted annually. Averaged across 14 trials in southern Illinois, corn yielded about 15 bushels per acre more than grain sorghum (Table 5.01). In general, grain sorghum yields more than corn when corn yields less than 100 bushels per acre, and less than corn when corn yields more than 100 bushels per acre. This illustrates the advantage that grain sorghum may have under unfavorable weather conditions and indicates that grain sorghum may provide more yield stability than corn if corn often yields less than 100 bushels per acre.

Table 5.01. Average Corn and Grain Sorghum Yields from Hybrid Comparison Trials in Southern Illinois, 1991–1995

Location	Corn	Grain sorghum
Brownstown[a]	128	114
Carbondale[b]	94	114
Dixon Springs[c]	168	116
Average	130	115

[a]1992 data are not included due to failure of grain sorghum trial.
[b]Trials were at Ina in 1991–92.
[c]Trials are located in productive bottomland.

Fertilization

The phosphorus and potassium requirements of grain sorghum are similar to those of corn. The response to nitrogen is somewhat erratic, due largely to the extensive root system's efficiency in taking up soil nutrients. For this reason, and because of the lower yield potential, the maximum rate of nitrogen suggested is about 125 pounds per acre. For sorghum following a legume such as soybeans or clover, this rate may be reduced by 20 to 40 pounds.

Hybrids

The criteria for selecting grain sorghum hybrids are very similar to those for selecting corn hybrids. Yield, maturity, standability, and disease resistance are all important. Consideration should also be given to the market class (endosperm color) and bird resistance, which may be associated with palatability to livestock. Performance tests of commercial grain sorghum hybrids are conducted at three locations in southern Illinois, and results are available (in the same report as the commercial corn hybrid yields) in Extension offices in December. Because of the limited acreage of grain sorghum in the eastern United States, most hybrids are developed for the Great Plains and may not have been extensively tested under Midwest conditions.

Planting

Sorghum should not be planted until soil temperature is at least 65°F. In the southern half of the state, mid-May is considered the starting date; late May to June 15 is the planting date in the northern half of the state. Such late planting—along with a shorter, cooler growing season—means that hybrids used in northern Illinois must be early-maturing.

Sorghum emerges more slowly than corn and requires relatively good seed-soil contact. Planting depth should not exceed 1½ inches, and about 1 inch is considered best. Because sorghum seedlings are slow to emerge, growers should use caution when using reduced- or no-till planting methods. Surface residue usually keeps the soil cooler and may harbor insects that can attack the crop, causing serious stand losses, especially when the crop is planted early in the season.

Row Spacing

Row-spacing experiments have shown that narrow rows produce more than wide rows (Table 5.02). Drilling in 7- to 10-inch rows works well if weeds can be controlled without cultivation, but if weed problems are expected, wider rows that will allow cultivation may be a better choice than drilled grain sorghum.

Plant Population

Because grain sorghum seed is small and some planters do not handle it well, there is a tendency to plant based on pounds of seed per acre rather than by number of seeds. This usually results in overly dense plant populations that can cause lodging and yield loss. Aim for a plant stand of 50,000 to 100,000 plants per acre, with a lower population on droughtier soils. Four to 6 plants per foot of row in 30-inch rows at harvest and 2 to 4 plants per foot in 20-inch rows are adequate. Plant 30 to 50 percent more seeds than the intended stand. Sorghum may also be drilled using 6 to 8 pounds of seed per acre. When drilling, be sure not to use excessive seed rates; plant stands when drilled should not be much higher than those in rows.

Weed Control

Because emergence of sorghum is slow, controlling weeds presents special problems. Suggestions for chemical control of weeds are given in the back of this handbook. As with corn, a rotary hoe is useful before weeds become permanently established.

Table 5.02. Yield of Grain Sorghum as Affected by Row Spacing in a Missouri Trial

Row spacing (in.)	Yield (bu/acre)
7	121
14	118
21	103
28	98
35	89

NOTE: Data are 3-year averages.

Harvesting and Storage

Timely harvest is important. Rainy weather after sorghum grain reaches physiological maturity may cause sprouting in the head, weathering (soft and mealy grain), or both. Harvest may begin when grain moisture is 20 percent or greater, if drying facilities are available. Sorghum dries very slowly in the field. Because sorghum does not die until frost, the use of a desiccant (sodium chlorate) can reduce the amount of green plant material going through the combine, making harvest easier.

Marketing

Before planting, check on local markets. Because the acreage in Illinois is limited, many elevators do not purchase grain sorghum.

Grazing

After harvest, sorghum stubble may be used for pasture. Livestock should not be allowed to graze for one week after frost because the danger of prussic acid or hydrocyanic acid (HCN) poisoning is especially high. Newly frosted plants sometimes develop tillers high in prussic acid.

Author

Emerson D. Nafziger
Department of Crop Sciences

Chapter 6. Cover Crops and Cropping Systems

While two crops, corn and soybeans, are grown in 2-year rotations in most cultivated fields in Illinois, recent "freedom to farm" legislation, along with concerns about the existing cropping patterns, has some farmers thinking about trying some different cropping systems. Although there is little evidence to suggest that the 2-year rotation common in Illinois is less stable than cropping systems common elsewhere, farmers are trying alternatives in an attempt to spread risks and to learn about other possible uses of the land they farm.

Cover Crops

Rye, wheat, ryegrass, hairy vetch, and other grasses and legumes are sometimes used as winter cover crops in the Midwest. The primary purpose for using cover crops is to provide plant cover for soil to help reduce erosion during the winter and spring. Winter cover crops have been shown to reduce total water runoff and soil loss by 50 percent or more, although the actual effect on any one field will depend on soil type and slope, the amount of cover, the planting and tillage methods, and intensity of rainfall. A cover crop can protect soil only while it or its residue is present, and a field planted after a cover crop has been plowed under may lose a great deal of soil if there is intense rainfall after planting. The use of winter cover crops in combination with no-till corn may reduce soil loss by more than 90 percent. Cover crops can also help to improve soil tilth, and they often contribute nitrogen to the following crop.

The advantages of grasses such as rye as cover crops include low seed costs, rapid establishment of ground cover in the fall, vigorous growth, recovery of residual nitrogen from the soil, and good winter survival. Most research has shown, however, that corn planted into a grass cover crop often yields less than when grown without a cover crop. There are several reasons for this. Residue from grass crops, including corn, has a high carbon-to-nitrogen ratio, so nitrogen from the soil is often tied up by microbes as they break down the residue. Second, a vigorously growing grass crop such as rye can dry out the surface soil rapidly, causing problems with stand establishment under dry planting conditions. When the weather at planting is wet, heavy surface vegetation from a cover crop can also cause soils to stay wet and cool, reducing emergence. Finally, chemical substances released during the breakdown of some grass crops have been shown to inhibit the growth of a following grass crop or of grass weeds. This phenomenon is known as allelopathy.

There are several benefits associated with the use of legumes as cover crops. Legumes are capable of nitrogen fixation; so, providing that they have enough time to develop this capability, they may provide some "free" nitrogen—fixed from the nitrogen in the air—to the following crop. Most leguminous plants have a lower carbon-to-nitrogen ratio than grasses, and soil nitrogen will not be tied up as much when legume plant material breaks down. On the negative side, early growth by legumes may be somewhat slower than that of grass cover crops, and many of the legumes are not as winter-hardy as grasses such as rye. Legumes seeded after the harvest of a corn or soybean crop thus often grow little before winter, resulting in low winter survivability, limited nitrogen fixation before spring, and ground cover that is inadequate to protect the soil.

Hairy vetch, at least in the southern Midwest, has usually worked well as a winter cover crop. It offers the advantages of fairly good establishment, good fall growth, and vigorous spring growth, especially if it is planted early (during the late summer). When allowed to make considerable spring growth, hairy vetch has provided as much as 80 to 90 pounds of nitrogen per acre to the corn crop that follows. One disadvantage to hairy vetch is its lack of sufficient winterhardiness; severe cold without snow cover

will often kill this crop in the northern half of Illinois, especially if it has not made at least 4 to 6 inches of growth in the fall. The seed rate of 20 to 40 pounds per acre, with seed costs ranging up to $1 per pound, can make use of this crop quite expensive; some farmers in the Midwest are growing their own seed to reduce the expense. Hairy vetch can also produce a considerable amount of hard seed, which may not germinate for 2 or 3 years, at which time it may be a serious weed, especially in a crop such as winter wheat. Other legume species that may be used as winter cover crops include mammoth and medium red clovers, alfalfa, and ladino clover.

To get the maximum benefit from a legume cover crop, such crops must be planted early enough to grow considerably before the onset of cold weather in the late fall. The last half of August is probably the best time for planting these cover crops. They can be aerially seeded into a standing crop of corn or soybeans, although dry weather after seeding may result in poor stands of the legume. Some attempts have been made to seed legumes such as hairy vetch into corn at the time of the last cultivation. This practice may work occasionally, but a very good corn crop will shade the soil surface enough to prevent growth of a crop underneath its canopy, and cover crops seeded in this way will often be injured by periods of dry weather during the summer. All things considered, the chances for successfully establishing legume cover crops are best when they are seeded into small grains during the spring or after small grain harvest, or when they are planted on set-aside or other idle fields.

There is some debate as to the best management of cover crops before planting field crops in the spring. There is usually a trade-off of benefits: Spring planting delays will allow the cover crop to make more growth (and to fix more nitrogen in the case of legumes), but this extra growth may be more difficult to kill, and it sometimes depletes soil moisture. Most indications are that killing a grass cover crop several weeks before planting is preferable to killing it with herbicide at the time of planting. Legumes can also create some of the same problems as grass cover crops, especially if they are allowed to grow past the middle of May.

Research at Dixon Springs in southern Illinois has illustrated both the potential benefits and possible problems associated with the use of hairy vetch. In these studies, hairy vetch accumulated almost 100 pounds of dry matter and about 2.6 pounds of nitrogen per acre per day from late April to mid-May (Table 6.01). The best time to kill the cover crop with chemicals and to plant corn, however, varied considerably among the 3 years of the study. On average, corn planted following vetch yielded slightly more when the vetch was killed 1 or 2 weeks before planting (Table 6.02). Also, corn planted in mid-May yielded more than corn planted in early May, primarily due to a very wet spring in 1 of the 3 years, in which vetch helped to dry out the soil. Vetch also dried out the soil in the other 2 years, but this proved to be a disadvantage because moisture was short at planting. The conclusions from this study were that vetch should normally be killed at least a week before planting and that planting should not be delayed much past early May because yield decreases due to late planting can quickly overcome benefits of additional vetch growth.

Table 6.01. Dry Matter and Nitrogen Contents of Hairy Vetch Killed by Herbicide at Dixon Springs, 1989–1991

Kill date	Dry matter (lb/acre)	Nitrogen (lb/acre)
Late April	1,300	55
Early May	2,509	85
Mid-May	3,501	115

Table 6.02. Effect of Vetch Kill Date and Corn Planting Time on Corn Yield at Dixon Springs, 1989–1991

	Vetch kill date	
Corn planting time	1 to 2 weeks before corn planting	At corn planting
Early May	116	114
Mid-May	129	125
Late May	85	N/A

Although the amount of nitrogen contained in the cover crop may be more than 100 pounds per acre (Table 6.01), the rate applied to a corn crop following the cover crop cannot be reduced one pound for each pound of nitrogen contained in the cover crop. A study in Illinois (*Journal of Production Agriculture*, Vol. 7, No. 1, 1994) demonstrated that the economically optimum nitrogen rate dropped by only about 20 pounds per acre when a hairy vetch cover crop was used, even though the hairy vetch contained more than 70 pounds of nitrogen per acre. This was due to the fact that yields were slightly higher (about 3 bush-

els per acre) following cover crops—even at high rates of nitrogen (Figure 6.01)—showing that not all of the cover crop benefit was its contribution of nitrogen. Even including the higher yield and lower nitrogen requirement, however, these researchers concluded that the use of hairy vetch was not economically justified. In the same study, rye caused a substantial yield loss (Figure 6.01), and it would be difficult to justify the use of rye based on these results.

Whether to incorporate cover-crop residue is debatable, with some research showing no advantages to incorporation and other results showing some benefit. Incorporation may enhance the recovery of nutrients such as nitrogen under some weather conditions, it may offer more weed control options, and it will help in stand establishment, both by reducing competition from the cover crop and by providing a better seedbed. On the other hand, incorporating cover-crop residue removes most or all of the soil-retaining benefit of the cover crop during the time between planting and crop canopy development, a period of high risk for soil erosion caused by rainfall. Tilling to incorporate residue can also stimulate the emergence of weed seedlings. One alternative to tillage for residue management is to have livestock graze off most of the top growth before planting.

Cropping Systems

The term *cropping system* refers to the crops and crop sequences and the management techniques used on a particular field over a period of years. This term is not

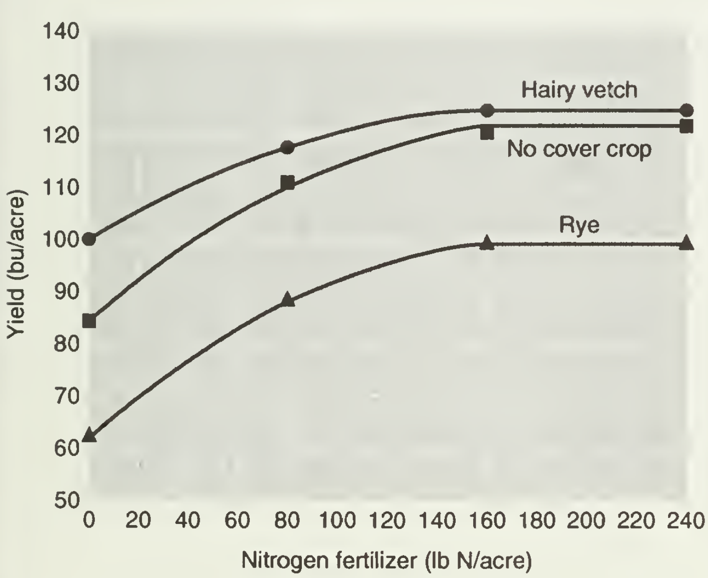


Figure 6.01. The effect of nitrogen fertilizer on grain yield of a summer grain crop (corn or grain sorghum) following either a hairy vetch or rye cover crop or fallow. Data are from five separate trials in Illinois, 1990–1991.

a new one, but it has been used more often in recent years in discussions about sustainability of our agricultural production systems. Several other terms have also been used during these discussions:

- **Allelopathy** is the release of a chemical substance by one plant species that inhibits the growth of another species.
- **Double-cropping** (also known as sequential cropping) is the practice of planting a second crop immediately following the harvest of a first crop, thus harvesting two crops from the same field in 1 year. This is a case of **multiple cropping**.
- **Intercropping** is the presence of two or more crops in the same field at the same time, planted in an arrangement that results in the crops competing with one another.
- **Monocropping** refers to the presence of a single crop in a field. This term is often used incorrectly to refer to growing the same crop year after year in the same field.
- **Relay intercropping** is a technique in which different crops are planted at different times in the same fields. An example would be dropping cover-crop seed into a standing soybean crop.
- **Strip cropping** is the presence of two or more crops in the same field, planted in strips such that most plant competition is within each crop, rather than between crops. This practice has elements of both intercropping and monocropping, with the width of the strips determining the degree of each.

Crop rotations, as a primary aspect of cropping systems, have received great attention in recent years, with many people contending that most current rotations are unstable and (at least indirectly) harmful to the environment and are therefore not sustainable. During the past 50 years, the number and complexity of crop rotations used in Illinois have decreased as the number of farms producing forages and small grains has declined. The corn-soybean rotation (with only one year of each crop) is now by far the most common one in the state. Although some contend that this crop sequence barely qualifies as a rotation, it offers several advantages to growing either crop continuously. These benefits include more weed control options and, often, fewer difficult weed problems, fewer insect and disease buildups, and less nitrogen fertilizer use than with continuous corn. Primarily because of these reasons (and others, some poorly understood), both corn and soybeans grown in rotation yield about 10 percent more than if they were grown continuously. Growing these two crops

in rotation also allows for more flexibility in marketing, and it offers some protection against weather- and pest-related problems in either crop.

The specific effects of a corn-soybean rotation on nitrogen requirements are discussed in Chapter 11 of this handbook. Figure 11.06 provides data on the effect of the previous crop on corn yields and on the nitrogen requirements of the corn crop. These data show that, except in the case of alfalfa, most of the effect of the previous crop on corn yields could be overcome with the use of additional nitrogen. Other studies also have shown that the yield differential due to crop rotation can be overcome partially by additional nitrogen, but the differential usually cannot be eliminated.

One frequent question is whether input costs can be reduced by using longer-term, more diverse crop rotations. Studies into this question have compared continuous corn and soybean and the corn-soybean rotation with rotations lasting 4 or 5 years that contain small grains and legumes, either as cover crops or as forage feed sources. Like the corn-soybean rotation, certain longer rotations can reduce pest-control costs, while including an established forage legume can provide considerable nitrogen to a succeeding corn crop (Figure 11.06). At the same time, most of the longer-term rotations include forage crops or other crops with smaller, and perhaps more volatile, markets than corn and soybeans. Lengthening rotations to include forages will be difficult unless the demand for livestock products increases. Such considerations will continue to favor production of crops such as corn and soybeans.

Author

Emerson D. Nafziger
Department of Crop Sciences

Chapter 7. Alternative Crops

Many alternative crops could be grown in Illinois, but they have not been produced commercially. A few have been produced on a limited scale and are sold in limited quantities to local markets. Many alternative crops are associated with high market prices or high income potential per acre and thus are eye-catching to farmers who might learn about them. Upon investigation, such crops often have requirements which cannot be met under Illinois conditions, have high costs of production, or have no established or very limited markets.

Before undertaking production of an alternative crop, study market availability, demand, and growth potential. Crops with limited demand can easily become surplus in supply, driving down previously high prices. Unless alternative crops are desired by large populations, potential market expansion is limited. Delivery to a local market is most desirable, but many alternative crops must be transported great distances to markets—reducing profitability. Market factors must be considered first with alternative crops!

Some alternative crops can be used on-farm, perhaps substituting for purchased livestock feed. If production cost is sufficiently low, it may be possible to increase overall farm profitability with an alternative crop. The feeding value of the alternative crop should be included in such a consideration: While some crops can substitute for protein supplements, they may not result in equal animal gain or performance.

It is possible to produce a number of alternative crops in Illinois, but their optimum yields may be obtained under different climatic regimes. Various types of beans can be grown in Illinois, but because of temperature and rainfall patterns, yield may be impaired, or disease may take a toll on yield or quality.

Specialized equipment and facilities—or a large supply of inexpensive labor—may be needed to produce an alternative crop. Unless equipment or special facilities are used across many acres of a crop, the cost will be prohibitive. Some alternative crops require large labor supplies not available in the Corn Belt. Success of many crops in foreign countries is due to abundant low-cost labor.

Profitability of producing alternative crops is the fundamental consideration for farmers. Unless economically viable on-farm consumption is possible, market demand and delivery points will determine income potential from each unit of any crop harvested. Highest yield from any crop will occur in a specific environment, but Illinois cannot provide the environments needed by many crops. Equipment and special facilities can be costly, and labor for some crops may not be affordable. Many factors can take profitability out of what may initially appear to be an exceptional farming opportunity.

Table 7.01 lists alternative crops which might be produced on Illinois farms. Information is provided on the botany, use, environmental needs, and potential problems for each crop. In all cases, the crops do not have large or established markets in Illinois. A few may have limited local markets, perhaps requiring the producer to market the crop directly to the consumer. More information on the crops listed can be obtained from *Alternative Field Crops Manual* (available from the Center for Alternative Plant and Animal Products, 340 Alderman Hall, University of Minnesota, St. Paul, MN 55108).

Sunflower, canola, and buckwheat crops have been produced on Illinois farms in recent years. Brief overviews of these crops and their production requirements are provided in subsequent sections.

Sunflower

Sunflower is an alternative crop which some Illinois farmers have produced profitably. Interest seems to be stimulated following drought years which suppress corn and soybean yields. Two kinds of sunflowers can be produced in Illinois: the oil type and the

Table 7.01. Alternative Crop Characteristics, Uses, and Considerations

Crop	Botany	Uses	Environmental needs	Potential problems
Adzuki bean	Legume; indeterminate growth habit; 110 to 120 days to maturity.	Food—confectionery items, fillings for bread.	Similar to soybean and drybeans.	Limited varieties; disease; limited markets.
Amaranth	Relative of red root pigweed; 5 to 7 ft tall.	Grain, forage, and green leafy vegetable.	Widely adapted to Midwest and western U.S. areas.	Uniform varieties not available; no herbicides labeled for crop; harvest losses; limited markets.
Broomcorn	Annual type of sorghum; 6 to 15 ft tall.	Long panicle branches used to make brooms.	Warm summer, soil moist and fertile—widely adapted.	Harvest and curing of fiber is very labor intensive; disease problems; limited markets.
Buckwheat	Indeterminate growth; will not die until killed by frost; harvest in 10 to 12 weeks.	Nutritious grain used for human food and livestock; smother crop or green manure.	Cool and moist climate; tolerates low fertility better than other grains.	Limited varieties available; seed shatter easily; limited markets.
Canola	Edible type of rape; spring and winter growth habits available.	Nutritious oil in grain; meal fed to livestock; forage use.	Well-drained, fertile soil; cool temperature range; cannot tolerate water-saturated soil.	May not survive winter in Illinois; timely planting in a corn-soybean rotation; seed shatter easily; limited delivery points in the Midwest.
Chickpea	Annual legume up to 40 in. tall; produces protein-rich seed; fairly drought resistant.	Soups and salads; can be fed to livestock.	Temperature of 70° to 80°F optimum; fertile soil with good drainage.	Excess water induces disease and lodging; limited markets.
Cowpea	Annual legume, known as blackeye pea; produces protein-rich seed.	Grain, fresh vegetable, or forage for livestock.	Adapted to humid tropics and temperate zones; tolerant of heat and drought, but not frost; needs well-drained soil.	Disease, nematodes, and virus problems can occur; specialized harvest equipment required for fresh harvesting; limited markets in the Midwest.
Crambe	Annual herb up to 40 in. tall; produces seed with inedible oil used by industry.	Manufacture of plastic, nylon, adhesives, and synthetic rubber.	Cool season; well-drained, fertile soil; cannot tolerate water-saturated soil.	No developed market; seed meal has little value; limited varieties available; no herbicide or insecticide labeled for crop.

Table 7.01. Alternative Crop Characteristics, Uses, and Considerations (cont.)

Crop	Botany	Uses	Environmental needs	Potential problems
Fababean	Annual legume; takes 80 to 120 days to mature; seedlings frost-tolerant; seed size varies greatly by variety.	Human food; livestock feed; forage or silage.	Cool, moist conditions; hot weather is injurious; well-drained soil; does not tolerate waterlogged soil conditions.	Negligible demand in the U.S., thus limited markets; no insecticide or herbicide labeled for the crop.
Ginseng	Perennial herb prized in East Asian cultures for its medicinal properties.	In East Asia in soft drinks, toothpaste, tea, and candy; sold as extracts, crystals, and powder capsules.	Moist climate; 70 to 90% shade; soil high in organic matter, with pH near 5.5.	Disease and insect problems; shade structures, labor, and time make production expensive; harvest is at least 3 years after planting.
Kenaf	Annual fiber crop native to Africa; 8 to 14 ft tall.	Fiber for paper, cardboard, rope, twine, rugs, and bagging; forage.	Widely adapted, but long growing seasons with high temperatures and abundant rainfall yield best.	Limited varieties, with none developed for the Midwest; specialized equipment needed for harvest; markets lacking.
Lentil	Cool season legume grain crop; 12 to 20 in. tall; seed varied in color; stems tend to lodge.	Soups, stews, and salads.	Cool temperatures with 10 to 12 in. precipitation annually (seedlings frost-tolerant); soil with good drainage required.	Plants are weak competitors, thus weed control is essential; lodging of stems slows harvest; volatile price; limited market opportunities.
Lupine	Annual legume crop with good protein content; older types had bitter alkaloids.	Flour and pasta; feed for dairy cows, lambs, and poultry, but not swine.	Cool season; relatively tolerant of spring frost; well-drained soil with pH below 7.	Poor competitor with weeds; very few herbicides cleared for use; diseases likely with excess moisture; seed costs are high (3x soybean); limited markets.
Millet	Annual grass up to 4 ft tall; several types, with proso, foxtail, and some barnyard types grown in the Midwest.	Bird food and livestock feed; hay and silage.	Warm temperatures (frost sensitive); well-drained, loamy soil; will not tolerate waterlogged soil or extreme drought.	Limited herbicides labeled; limited markets available through bird food suppliers.

Table 7.01. Alternative Crop Characteristics, Uses, and Considerations (cont.)

Crop	Botany	Uses	Environmental needs	Potential problems
Mung bean	Annual legume; 1 to 5 ft tall; upright or viney types; seed color varies with variety.	Bean sprouts or canned for human food; livestock feed.	Warm season like soybean; fertile, well-drained soil with good internal drainage and pH less than 7.2.	Many broadleaf herbicides damage the crop; pod maturity not uniform; seed costs higher than soybean; limited market opportunities.
Safflower	Annual oilseed; produces a high-quality edible oil low in saturated fatty acids.	Primarily oil, but also protein meal and birdseed.	Warm, sunny, less than 15 in. rain/year; dry weather during flower and seed fill; deep, fertile, well-drained soil.	Broadleaf weeds are difficult to control; wet weather can induce disease; no established market.
Spelt	Wheat relative with protein content similar to oats; growth habit like winter wheat.	Feed grain, pasta, and high-fiber cereals; can replace soft red winter wheat in baked goods.	Typical Midwest climates; is reported more winter-hardy than most soft red winter wheat; grows on sandy and poorly drained soils.	Feed value could be lower than oats, as test weight is sometimes lower; no established market.
Sunflower	Annual; produces high-quality edible oil; world's third-largest oilseed crop.	Vegetable oil, snack food, birdseed, protein meal, soaps, detergent, plastics, adhesives, and paints.	Semiarid regions; tolerates high and low temperatures; can survive drought but is inefficient water user; grows on wide range of soil types.	Bird, disease, and insect problems can limit yield; modified combine needed for efficient harvest; limited local markets in the Midwest.
Triticale	Created from the cross of wheat and rye; spring and winter types grow like wheat and rye.	Livestock feedgrain, forage, baked goods; inferior to wheat.	Needs of winter types similar to fall-planted wheat and rye; spring types need conditions similar to spring oats, barley, and wheat.	Ergot disease may occur with spring plantings; other diseases may occur; markets limited.

confectionery, or non-oil, type. Production practices tend to be the same, but end uses of the grain differ.

Oilseed sunflower produces a relatively small seed with an oil content of up to 50 percent. The hull on the grain is thin and dark colored and adheres tightly to the kernel. Oil from this type of sunflower is highly regarded for use as a salad and frying oil. Meal from the kernel is used as a protein supplement in livestock rations. Sunflower meal is deficient in lysine, and thus except for ruminant animals, it cannot be used as the only source of protein.

The confectionery (non-oil) type of sunflower is used for human and bird food. The seed is larger than the oil type, with a considerably lower oil content. The hull is lighter in color and usually striped, and the hull separates easily from the kernel.

Sunflower planting coincides with that of corn in Illinois. Many hybrids offered for sale will reach physiologic maturity in only 90 to 100 days and thus can be planted following harvest of small grain crops. Use of sunflower as a double-crop may be a good choice if soybean cyst nematode is a pest, because sunflower is not attacked by cyst nematode.

Populations of 20,000 to 25,000 plants per acre are suitable for oilseed sunflower types produced on soils

with good water-holding capacity. Stands of 16,000 to 20,000 per acre are appropriate for coarser textured soils with low water-holding capacity. The confectionery-type sunflower should be planted at lower populations to help ensure production of large seed. Planting of seed should be at 1½- to 2-inch depth, similar to placement for corn. Performance will tend to be best in rows spaced at 20 to 30 inches.

A seed moisture of 18 to 20 percent is needed to permit sunflower harvest. Once physiologic maturity of seed occurs (at about 40 percent moisture), a desiccant can be used to speed drying of green plant parts. Maturity of kernels occurs when the backs of heads are yellow, but the fleshy head and other plant parts take considerable time to dry to a level that permits combine harvest. A conventional combine head can be used for harvest, with losses reduced considerably if special panlike attachments extending from the cutter bar are used. Long-term storage of sunflower is feasible, but levels of less than 10 percent moisture need to be maintained.

Locating a market for sunflower is important before producing the crop. A limited number of marketing sites exist for oil-type sunflower, but most confectionery sunflowers are produced under contract for local feed distributors or health food stores. Because the head containing seed is exposed at the top of the plant, insects, disease, and birds can be pest problems. The location of sunflower fields relative to wooded areas will have an impact on the extent of bird damage.

Canola (Oilseed Rape)

Canola is a member of the mustard family with unique chemical properties allowing consumption of edible oil and protein-rich meal from the seed. Rape, from which canola was selected, is a crop which has been used as an oilseed in many countries for centuries. Unlike rape, canola has a low erucic acid content in the oil and low levels of glucosinolates in the meal produced from the seed. Only since 1985 has canola been approved for consumption in the United States.

Varieties of canola with spring and winter growth habits are available, but the winter type is more likely to succeed in Illinois because hot weather occurs during seed production when spring types are grown. Winterhardiness under Illinois conditions has proven to be a problem for the winter types, which are planted in the fall shortly before wheat is typically seeded.

Site selection is critical to successful production of canola, because waterlogged soil cannot be tolerated. Only fields with good drainage should be used; excess moisture (ponding) will kill the crop.

Planting 2 or 3 weeks in advance of normal wheat planting time is adequate for plant establishment, provided that fall temperatures do not arrive unusually early. The very small seeds need to be planted shallowly with a grain drill at a rate of only 5 to 6 pounds per acre. Canola needs adequate time to become established before fall temperatures decline, but it does not need to develop excessively. Plants with 8 to 10 leaves are considered adequate for winter survival. A tap root 5 to 6 inches deep generally develops with desired levels of topgrowth in the fall.

Soil-fertility needs of canola are similar to winter wheat, with a small amount of nitrogen applied in the fall to stimulate establishment and a larger topdress nitrogen application in the early spring to promote growth. Too much nitrogen available in the fall can delay the onset of dormancy of canola, putting it at greater risk for winter injury. Excess fertility can accentuate lodging tendencies.

Growth of canola resumes early in the spring, with harvest maturity being reached about the same time as winter wheat. Harvest needs to be done in a timely manner, for seeds tend to shatter easily from pods. Only the top portion of the plant containing the seed pods is harvested. Combining works well when seeds reach 10 percent moisture, but further drying of seeds (to 9 percent moisture or less) and occasional aeration are needed for storage. As seeds are very small, tight wagons, trucks, and bins are needed for transportation and storage.

Locating a nearby delivery site for canola is presently a problem.

Buckwheat

Nutritionally, buckwheat is a very good grain, with an amino acid composition superior to all cereals, including oats. Producing the crop as a livestock feed is possible, but markets for human consumption tend to be small. An export market exists in Japan, where noodles are made from the grain.

Buckwheat has an indeterminate growth habit; consequently, it grows until frost terminates growth that is most favored by cool and moist conditions. In a short period (75 to 90 days), it can produce grain ready for harvest. High temperatures and dry weather during flowering can seriously limit grain formation. Little breeding work has been done to enhance yield potential; it is naturally cross-pollinated and cannot be inbred because of self-incompatibility. A limited number of varieties are available.

Because it produces grain in a short time, buckwheat can be planted as late as July 10 to 15 in northern Illinois and during late July in southern parts of the state. Rapid vegetative growth of the plant provides good competition to weeds. Fertility demands are not high, so buckwheat may produce a better crop than other grains on infertile, poorly drained soils.

With the exception of those that can use the crop for livestock feed, producers should determine market opportunities before planting buckwheat. A few grain companies in the Midwest handle the crop for export to Japan.

Other Crops

There is plenty of opportunity for individuals or small groups to explore production and marketing of the alternative crops described here. However, it is difficult to imagine a substantial shift away from corn, soybeans, or wheat in favor of any of these crops. People and livestock require very large amounts of carbohydrates, protein, and edible oil to meet dietary needs. A good balance of these is provided by the crops now grown in Illinois.

Author

Gary E. Pepper
Department of Crop Sciences

Chapter 8.
Hay, Pasture, and Silage

Thick, vigorous stands of grasses and legumes are needed for high yields. A thick stand of grass will cover nearly all the ground. A thick stand of alfalfa is about 30 plants per square foot at the end of the seeding year, 10 to 15 plants per square foot the second year, and 5 to 7 plants per square foot in succeeding years.

Research has shown that stem density is a better indicator of potential yield than plants per square foot. A stem count can be taken when the plants are 4 to 6 inches tall and is done by counting any stem the mower would cut. Fifty-five stems per square foot is optimum, and if there are fewer than 39 stems per square foot, consider tearing up the stand. If evaluating a stand in the early spring, you may have to base decisions on the number of plants per square foot, since a stem count may not be possible.

Fall is the best time to make stand evaluations. A health assessment of the crown and root needs to be a part of the evaluation.

Vigorous stands are created and maintained by choosing disease- and insect-resistant varieties that grow and recover quickly after harvest, by following good seeding practices, by fertilizing adequately, by harvesting at the optimum time, and by protecting the stand from insects. Soil drainage characteristics, along with winter hardiness and drought tolerance of the species, also affect the vigor of the stand.

Establishment

Spring seeding date for hay and pasture species in Illinois is late March or early April, as soon as a seedbed can be prepared. Exceptions are seedings that are made in a fall-seeded, winter annual companion crop; for such seedings, seed hay and pasture species about the time of the last snow.

Sowing hay and pasture species into spring oats in the spring should be done when the oats are seeded, as early as a seedbed can be prepared.

Spring seedings are more successful in the northern half of Illinois than in the southern half. The frequency of success in the southern one-quarter to one-third of the state indicates that late-summer seedings may be more desirable than spring seedings.

Late-summer seeding date is August 10 in the northern quarter of Illinois, August 30 in central Illinois, and September 15 in the southern quarter of Illinois. Seedings should be made close to these dates, and no more than 5 days later, to ensure that the plants become well established before winter. Late-summer seedings that are made extremely early may suffer from drought following germination or invasion of summer annual weeds when plentiful moisture is present.

Frost seeding (or overseeding) is the surface broadcast placement of seed into existing vegetation in late winter or very early spring. Success of this seeding method is dependent on soil freeze-thaw cycles, a late snowfall, spring rain, and the management given to the existing vegetation prior to and after seeding. Red clover and ladino clover, plus ryegrass and orchardgrass, are two legumes and grasses, respectively, that are well adapted to frost seeding.

Seeding rates for hay and pasture mixtures are shown in Table 8.01. These rates are for seedings made under average conditions, either with a companion crop in the spring or without a companion crop in late summer. Higher rates may be used to obtain high yields from alfalfa seeded without a companion crop in the spring. Seeding rates higher than described in Table 8.01 have proven economical in northern and central Illinois when alfalfa was seeded as a pure stand in early spring and two or three harvests were taken in the seeding year. In northern and central Illinois, but not in south-central Illinois, seeding alfalfa at 18 pounds per acre has produced yields 0.2 to 0.4 ton higher than seeding at 12 pounds per acre. Selecting varieties with high yield potential, high seedling vigor, and rapid seeding growth rate helps obtain extra yield potential from the higher seeding rate.

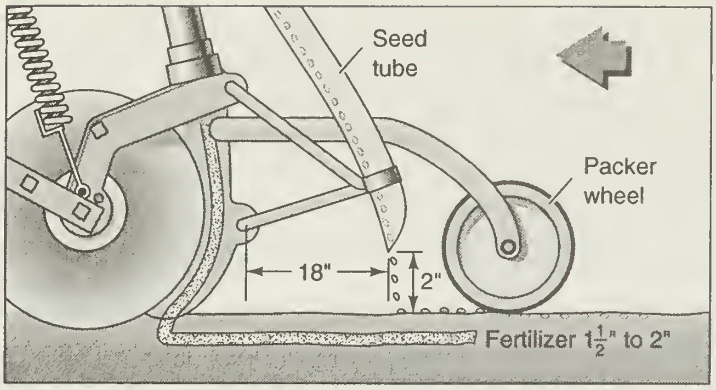


Figure 8.01. Placement of seed and high-phosphate fertilizer with grain drill.

The two basic methods of seeding are band seeding and broadcast seeding. With band seeding, a band of phosphate fertilizer (0-45-0) is placed about 2 inches deep in the soil with a grain drill; then the forage seed is placed on the soil surface directly above the fertilizer band (Figure 8.01). Before the forage seeds are dropped, the fertilizer should be covered with soil, which occurs naturally when soils are in good working condition. A presswheel should roll over the forage seed to firm the seed into the soil surface. Many seeds will be placed ⅛ to ¼ inch deep with this seeding method, an excellent depth for most forage legume and grass species.

With broadcast seeding, the seed is spread uniformly over a firm, prepared seedbed; then the seed is pressed into the seedbed surface with a corrugated roller. The fertilizer is applied at the early stages of seedbed preparation. The seedbed is usually disked and smoothed with a harrow. Most soil conditions are too loose after these tillage operations and should be firmed with a corrugated roller before seeding. The best seeding tool for broadcast seeding is the double corrugated roller seeder.

Which is the better seeding method? Illinois studies have shown that band seeding often results in higher alfalfa yields than broadcast seedings for August and spring seedings. Seedings on soils that are low in phosphorus yield more from band seeding than from broadcast seeding. Early seeding on cold, wet soils is favored by banded phosphorus fertilization. The greater yield from band seeding may be a response to abundant, readily available phosphorus from the banded fertilizer. Broadcast seedings may yield as high as band seedings when the soils are medium to high in phosphorus-supplying capacity and are well drained, so that they warm up quickly in the spring. Forage crop seeds are small and should be seeded no deeper than ⅛ to ¼ inch. They should be in close contact with soil particles. The double corrugated roller seeder and the band seeder with presswheels roll the seed into contact with the soil and are the best-known methods of seeding forages.

Fertilizing and Liming Before or at Seeding

Lime. Apply lime at rates suggested in Figure 11.05. If rate requirements exceed 5 tons, apply half before the primary tillage (in most cases, plowing) and half before the secondary tillage (harrowing or disking). For rates of less than 5 tons, make a single application, preferably after plowing, although applying either before or after plowing is acceptable.

Nitrogen (N). Nitrogen should not be applied for legume seedings on soils with an organic-matter content more than 2.5 percent. Applying as much as 20 pounds of nitrogen per acre may help ensure rapid seedling growth of legume-grass mixtures on soils with less than 2.5 percent organic matter. For seeding a pure grass stand, 50 to 100 pounds of nitrogen per acre in the seedbed are suggested. For band seeding, apply nitrogen with phosphorus through the grain drill. For broadcast seeding, apply broadcast with phosphorus and potassium during seedbed preparation.

Phosphorus (P). Apply all phosphorus at seeding time (Tables 11.22 and 11.25), or broadcast part of it with potassium. For band seeding, reserve at least 30 pounds of phosphate (P_2O_5) per acre to be applied at seeding time. For broadcast seeding, broadcast all the phosphorus with the potassium, preferably after primary tillage and before final seedbed preparation.

Potassium (K). Fertilize before or at seeding. Broadcast application of potassium is preferred (Tables 11.24 and 11.26). For band seeding, you can safely apply a maximum of 30 to 40 pounds of potash (K_2O) per acre in the band with phosphorus. The response to band fertilizer will be mainly from phosphorus unless the potassium soil test is very low (perhaps 100 pounds per acre or less). For broadcast seeding, apply all the potassium after the primary tillage. You can apply up to 600 pounds of K_2O per acre in the seedbed without damaging seedlings if the fertilizer is broadcast and incorporated.

Fertilization

Nitrogen. In Chapter 11, "Soil Testing and Fertility," see the subsection about nitrogen and Table 11.11.

Phosphorus. This nutrient may be applied in large amounts, which is adequate for 2 to 4 years. The annual needs of a hay or pasture crop are determined from yield and nutrient content of the forage harvested (Table 11.25). Grasses, legumes, and grass-

legume mixtures contain about 12 pounds of P_2O_5 (4.8 pounds of phosphorus) per ton of dry matter. Total annual fertilization needs include the maintenance rate (Table 11.25) and any needed build-up rate (Table 11.22).

Potassium. Because potassium helps the plant convert nitrogen to protein, grasses need large amounts of potassium to balance high rates of nitrogen fertilization. As nitrogen rates increase, the percentage of nitrogen in the plant tissue also increases. If potassium is deficient, however, some nitrogen may remain in the plant as nonprotein nitrogen.

Legumes feed heavily on potassium. Potassium, a key element in maintaining legumes in grass-legume stands, is credited with improving winter survival.

Annual potassium needs are determined from yield, nutrient content in the forage that is harvested, and nutrient build-up requirements of a particular soil (Tables 11.24 and 11.26). Grasses, legumes, and grass-legume mixtures contain about 50 pounds of K_2O (41.5 pounds of potassium) per ton of dry matter.

Boron (B). Symptoms of boron deficiency appear on second and third cuttings of alfalfa during droughty periods in some areas of Illinois. But yield increases from boron fertilization have been infrequent. Application of boron on soils with less than 2 percent organic matter is recommended for high-yielding alfalfa production in Illinois. If you suspect a boron deficiency, topdress a test strip in your alfalfa fields with 30 pounds per acre of household borax (3.3 pounds of boron). For general application, have boron added to the phosphorus-potassium fertilizer to apply 3 to 4 pounds of boron per acre. Apply boron each year of forage production except the last year if corn follows in the rotation.

Management

Seeding year. Hay and pasture crops seeded into a companion crop in the spring will benefit by early removal of the companion crop. Oats, wheat, or barley should be removed when the grain is in the milk stage. If these small grains are harvested for grain, it is important to remove the straw and stubble as soon as possible. As small-grain yields increase, the underseeded legumes and grasses face greater competition, and fewer satisfactory stands are established by the companion-crop method. Forage seedings established with a companion crop may have one harvest taken by late August in northern Illinois and occasionally twc harvests by September 10 in central Illinois and by September 25 in southern Illinois.

Spring-seeded hay crops and pastures without a companion crop should be ready for harvest 65 to 70 days after an early April seeding. Weeds very likely must be controlled about 30 days after seeding, unless a preemergence herbicide was used. Postemergence herbicides 2,4-DB, Buctril, and Pursuit are effective against most broadleaf weeds. Grassy weeds are effectively controlled by Poast Plus. Pursuit controls a few grassy weeds. Follow label directions. Leafhoppers often become a problem between 30 to 45 days after an early April seeding and must be controlled to obtain a vigorous, high-yielding stand.

Second and third harvests may follow the first harvest at 35- to 40-day intervals. The last harvest of the season should be in late August for the northern quarter of Illinois, by September 10 for the central section, and by September 20 for the southern quarter.

Established stands. Maximum dry-matter yield from alfalfa and most forages is obtained by harvesting or grazing the first cutting at nearly full bloom and harvesting every 40 to 42 days thereafter until September. This management produces a forage that is relatively low in digestibility. Such forage is suitable for livestock on maintenance rations, produces slow weight gain, and can be used in low-performance feeding programs. In contrast, high-performance feeding programs require a highly digestible forage. The optimal compromise between high digestibility and dry-matter yield of alfalfa is to harvest or graze the first cutting at the late-bud to first-flower stage and to make subsequent cuttings or grazings at 32- to 35-day intervals. Producers desiring high-quality alfalfa hay at first cutting are encouraged to use the scissor clip technique or the predictive equations for alfalfa quality (PEAQ) as a guide in selecting the harvest date. Both methods provide an in-field estimate of preharvest quality of standing alfalfa. They are not designed for ration balancing.

The scissor clip procedure involves taking clippings by hand at mower height in several places within a field early in the morning. Clippings should be taken twice a week, and each sample should be no more than 1 pound fresh weight. Deliver the sample to a forage quality–testing laboratory for analysis via NIRS. As a general guide, the first harvest should be taken when the relative feed value (RFV) based on the scissor clip analysis is 15 percent above what is desired; for example, harvest at RFV 170 to obtain RFV 150.

The PEAQ method predicts RFV and fiber by using a five-point maturity index to stage the most mature stem in a 2-square-foot area, plus the height of the tallest stem in the area. With the use of either an equation or a table, estimates of RFV and fiber are obtained. Samples are not submitted to a laboratory. PEAQ is an estimate of quality of the standing alfalfa, and harvest and storage losses are not accounted for.

Rotational grazing is essential to maintaining legumes in pastures. A rotational grazing program of 5 to 6 pastures should provide for 5 to 7 days of grazing and 30 to 35 days of rest. More intensive grazing, using 8 to 11 pastures, 3 to 4 days of grazing, and 30 to 33 days of rest, increases meat or milk production per acre but may not increase individual animal performance. Managing pastures intensively is a method many livestock producers in Illinois are adopting.

Because high levels of root reserves (sugars and starches) are needed for winter survival and vigorous spring growth, the timing of the fall harvest is critical. Following a harvest, root reserves decline as new growth begins. About 3 weeks after harvesting, root reserves are depleted to a low level, and the top growth is adequate for photosynthesis to support the plant's needs for sugars. Then root reserves are replenished gradually until harvest or until the plant becomes dormant in early winter. Harvests in September and October affect late-fall root reserves of alfalfa more than summer harvests do. After the September harvest, alfalfa needs a recovery period until late October to restore root reserves. On well-drained soils in central and southern Illinois, a "late" harvest may be taken after plants have become dormant in late October or early November. Fall dormancy is triggered or influenced by the variety and air and soil temperature.

Pasture Establishment

Many pastures can be established through a hay-crop program. Seedings are made on a well-prepared, properly fertilized seedbed. If it is intended that the hay crop becomes a pasture, the desired legume and grass mixture should be seeded. When grasses and legumes are seeded together, 2,4-DB or Buctril can be used for broadleaf weed control. Apply 2,4-DB or Buctril about 30 days after seeding when the legumes are 2 to 4 inches tall and the weeds less than 4 inches tall.

Pasture Renovation

Pasture renovation usually means changing the plant species in a pasture to increase the pasture's quality and productivity. Improving the fertility of the soil is basic to this effort. A soil test helps identify the need for lime, phosphorus, and potassium—the major nutrients important to establishing new forage plants.

Before seeding new legumes or grasses into a pasture, reduce the competition from existing pasture plants. Tilling, overgrazing, and herbicides—used singly or in combination—have proven useful in subduing existing pasture plants.

For many years, tilling (plowing or heavy disking) has been used to renovate pastures, but success has been variable. Major criticisms have been that tilling can cause soil erosion, that the pasture supply for the year of seeding is usually limited, and that a seeding failure would leave no available permanent vegetation for pasturing or soil protection.

No-till seeding of new pasture plants into existing pastures began when herbicides and suitable seeders were developed. The practice of using a herbicide to subdue existing pasture plants and then seeding with a no-till seeder has proven very successful in many research trials and farm seedings. Following are eight basic steps to no-till pasture renovation:

1. Graze the pasture intensively for 20 to 30 days before the seeding date to reduce the vigor of existing pasture plants.
2. Lime and fertilize, using a soil test as a guide. Soil pH should be between 6.5 and 7.0. Desirable test levels of phosphorus and potassium vary with soil type; phosphorus should be in the range of 40 to 50 pounds per acre, and potassium in the range of 260 to 300 pounds per acre. For more information, see Chapter 11.
3. One or 2 days before seeding, apply a herbicide to subdue the vegetation. Gramoxone Super (paraquat) and Roundup (glyphosate) are approved for this purpose.
4. Seed the desired species, using high-yielding varieties. Alfalfa and red clover are legumes with high-yield potential and are often the species seeded into a pasture that has a desirable grass species and in which Gramoxone Super is to be used in preference to Roundup. To change the grass species in the pasture, use Roundup at label rates. To seed, use a no-till drill that places the seed in contact with the soil.
5. Seedings may be made in early spring throughout the northern two-thirds of Illinois and in late August throughout the southern three-fourths of Illinois.
6. Apply insecticides as needed. Insects that eat germinating seedlings are more prevalent in southern Illinois than in northern Illinois, and an insecticide may be needed. Leafhoppers will usually appear throughout Illinois in early summer and remain during most of the growing season. They must be controlled where alfalfa is seeded, especially in spring-seeded pastures, because leafhopper feeding devastates new alfalfa seedlings. Several insecticides are approved; for more information, see the current *Illinois Agricultural Pest Management Handbook* chapter on "Insect Pest Management for Field

and Forage Crops." Well-established alfalfa plants are injured but not killed by leafhoppers; red clover and grass plants are not attacked by leafhoppers. White clover (ladino) and other nonpubescent clovers may be attacked by leafhoppers, causing stunting of plants, reddening, and bronzing of leaflets.

7. Initiate grazing 60 to 70 days after spring seedings and not until the next spring for late-August seedings. Spring-seeded alfalfa and red clover should be approaching 50 percent bloom at the first grazing. Alfalfa and red clover seeded in late August should be in the late-bud to first-flower stage of growth when grazing begins. Use rotational or intensive grazing management. Rotational grazing requires a maximum of 5 to 7 grazing days, 28 to 30 resting days, and 5 to 6 pastures per paddock. For higher-quality feed, higher yield and greater animal product per acre, and increased persistence of interseeded legumes, use intensive grazing management. To use this method, graze 1 to 3 days and rest 28 to 30 days. It requires 11 to 30 or more paddocks. Use one or two strands of electric fencing for interior barriers to separate paddocks. Movable fencing is very practical for interior fencing in intensive grazing management paddocks.
8. Fertilize pastures annually on the basis of estimated crop removal. Each ton of dry matter from a pasture contains about 12 pounds of phosphate (P_2O_5) and 50 to 60 pounds of potash (K_2O). Do not use nitrogen on established pastures where the sward is at least 30 percent alfalfa, red clover, or both. Because 20 to 80 percent of the nutrients grazed may be returned to the pasture in the form of urine and manure, fertilization rates for pastures will be less than for hay production. Rotational and intensive grazing management improves uniformity of distribution and utilization of manure and urine on pastures. The efficiency of nutrient recycling is increased, which reduces the need for supplemental fertilization. Soil-test pastures thoroughly every 4 years, and adjust the fertilization program according to the results. Usually less phosphate and potash are needed on pastures than hay fields.

Selection of Pasture Seeding Mixture

Alfalfa is the best species for increasing yield and improving the quality of pastures throughout Illinois. Consider using a "grazing type" of alfalfa, which has been specifically selected to tolerate grazing. Many seed companies have varieties available. Red clover, adapted throughout Illinois, has been an excellent legume for pastures in the southern region of the state. Red clover produces very well in the first 2 years after seeding but contributes very little after that. Birdsfoot trefoil establishes slowly and increases to 40 to 50 percent of the yield potential of alfalfa. Birdsfoot trefoil is best suited to the northern half of Illinois. It tolerates soils that are somewhat poorly drained, have a pH of 6.0 or higher, and have moderate phosphorus and potassium levels. Mixtures of alfalfa at 8 pounds and red clover at 4 pounds per acre or of birdsfoot trefoil at 4 pounds and red clover at 4 pounds per acre have demonstrated high yield. Red clover diminishes from the stand about the third year; and the more persistent species, alfalfa or birdsfoot trefoil, increases to maintain a high yield level for the third and subsequent years.

Pasture Fertilization

The yield and quality of many pastures can be improved by fertilization. The soil pH is basic to any fertilization program. Pasture grasses tolerate a lower soil pH than do hay and pasture legumes. For pastures that are primarily grass, the lowest pH should be 6.0. A pH of 6.2 to 6.5 is more desirable because nutrients are more efficiently used in this pH range than at lower pH values. Lime should be applied to correct the soil acidity to one-half plow depth. This liming is effective half as long as when a full rate is applied and plowed into the plow layer. Consequently, liming is required more often (but at lower rates) in pastures than in cultivated fields.

The need for nitrogen is based on the percentage of legumes in the pasture, as discussed in Chapter 11. Phosphorus and potassium needs are assessed by a soil test. Without a soil test, the best guess is to apply what the crop removes. Pasture crops remove about 12 pounds of phosphate (P_2O_5) and 50 pounds of potash (K_2O) per ton of dry matter removed. Very productive pastures yield 5 to 6 tons of dry matter per acre; moderately productive pastures yield 3 to 5 tons; and less productive pastures, 1 to 3 tons. Recycling of nutrients from urine and manure reduces the total nutrients removed from a pasture by 20 to 80 percent, varying with the intensity of pasture management. Soil-test every 4 years to monitor changes in the fertility status of pastures.

Pasture Management

Rotational grazing of grass pastures results in greater production (animal product yield per acre) than does continuous grazing, except for Kentucky bluegrass pastures. Pastures that include legumes need rotational

grazing to maintain the legumes. A rotational-grazing plan that works well is 5 to 7 days of grazing with 28 to 30 days of rest, requiring 5 or 6 fields. This plan provides the high-quality pasture needed by growing animals and dairy cows. A more intense grazing system for high-performance livestock and for high animal product per acre is a rotational grazing system of 8 to 11 fields, 3 to 4 days of grazing, and 30 to 33 days of rest per pasture field. A less-intensive and less-productive grazing plan for beef cow herds, dry cows, and stocker animals is 10 days of grazing with 30 days of rest, requiring 4 pastures.

When adopting a rotational or management-intensive pasture grazing system, consider the forage quality requirement of the livestock, estimate forage production and stocking density, determine the number of paddocks needed, remember to fence tonnage and not acres, and remain flexible. The amount of forage growth that can be removed per grazing period and the needed rest period will vary with the species and grazing season.

Weed control is usually needed in pastures. Clipping pastures after each grazing cycle helps in weed control, but herbicides may be needed for problem areas. Banvel and 2,4-D are effective on most broadleaf weeds. Banvel is more effective than 2,4-D for most conditions but has more restrictions. Thistles can usually be controlled by 2,4-D or Banvel, although repeated applications of the herbicide may be necessary. Multiflora rose may be controlled with Banvel applied in early spring, when the plant is actively growing, but before flower bud formation. Grazing and haying restrictions vary with most pesticides for different classes of livestock, for rates of pesticide application, and use of the animal product. Consult the label on the pesticide and/or reliable references supplied by the manufacturer and others, such as the current *Illinois Agricultural Pest Management Handbook.*

Species and Varieties

The University of Illinois has conducted a testing program of public and private forages for many years. The 1998 test field locations were Freeport (Stephenson County), Shabbona (DeKalb County), Urbana (Champaign County), Perry (Pike County), and Carlyle (Clinton County). The Freeport site is located on a dairy farm; the Carlyle site is hosted by a hay merchandiser; and the other locations are on University of Illinois Agronomy Research Centers.

The Department of Crop Sciences publishes yearly a report entitled *Forage Crop Variety Trials in Illinois.* This publication summarizes performance data by seeding year of forage species and varieties grown at the test field locations. The publication is available at Extension offices.

When selecting a variety you should consider yield potential, persistence, winterhardiness, disease and insect resistance, and forage quality.

Alfalfa is the highest-yielding perennial forage crop suited to Illinois, and its nutritional qualities are nearly unsurpassed. Alfalfa is an excellent hay-crop species and with proper management may be used in pastures, as already mentioned.

Bloat in ruminant animals often is associated with alfalfa pastures. Balancing soil fertility, including grasses in mixtures with alfalfa, maintaining animals at good nutritional levels, and using bloat-inhibiting feed amendments are methods to reduce or essentially eliminate the bloat hazard.

Many varieties of alfalfa are available. Many were developed privately; some were developed at public institutions. Private varieties usually are marketed through a few specific dealers. Not all varieties are available in Illinois.

Bacterial wilt is one of the major diseases of alfalfa in Illinois. Stands of susceptible varieties usually decline severely in the third year of production and may die out in the second year under intensive harvesting schedules. Moderate resistance to bacterial wilt enables alfalfa to persist as long as 4 or 5 years. Varieties listed as resistant usually persist beyond that.

Phytophthora root rot is a major disease of alfalfa grown on poorly drained soils, primarily in the northern half of Illinois. This disease attacks both seedlings and mature plants. The root develops a black lesion, which progresses and rots the entire root. In mature stands, shortened taproots are a symptom of this disease. Many alfalfa varieties with high-yield performance have resistance or moderate resistance to Phytophthora root rot.

Anthracnose is an important disease in the southern half of Illinois and may be important in northern Illinois during warm, humid weather. The disease causes the stem and leaves to brown, with the tip of the stem turning over like a hook. The fungus causes a stem lesion, usually diamond-shaped in the early stages, that enlarges to completely encircle the stem. Many alfalfa varieties with high-yield performance have resistance or moderate resistance to anthracnose.

Verticillium wilt is a root-rot disease similar to bacterial wilt. Verticillium wilt develops slowly, requiring about 3 years before plant loss becomes noticeable. Associated with cool climates and moist soils, this fungus is gradually spreading southward in Illinois. Producers in the northern quarter of Illinois should seek resistant varieties and producers in the rest of the northern half of the state should observe their fields

and consider using resistant varieties when seeding alfalfa. Many alfalfa varieties with high-yield performance have resistance or moderate resistance to verticillium wilt.

Other diseases and insects are problems for alfalfa, and some varieties of alfalfa have particular resistance to these problems. You should question your seed supplier about these attributes of the varieties being offered to you.

Alfalfa produces a water-soluble toxin that reduces the germination and growth of new alfalfa seedings. This is called *autotoxicity*. At least one-half of the toxin is found in the above-ground plant parts. When a stand is more than 1 year of age, enough of the toxin may be present to cause damage to new seedings reestablished into that field. In this situation, ideally a grass crop (corn is best) should be grown for 1 year before reestablishing to alfalfa. This allows the toxin time to degrade and leach away from the root zone.

Alfalfa stands less than one year of age have not produced enough of the toxin, so if necessary, alfalfa could be reestablished.

Red clover (medium red clover) is the second most important hay and pasture legume in Illinois. Although it does not have the yield potential of alfalfa under good production conditions, red clover can persist in wetter and more acidic soils and under more shade competition than can alfalfa. And, although red clover is physiologically a perennial, root and crown diseases limit the life of red clover to 2 to 3 years. Many new varieties have an increased resistance to root and crown diseases and are expected to be productive for at least 3 years.

Red clover does not have as much seedling vigor or as rapid a seedling growth rate as alfalfa. Red clover thus does not fit into a spring seeding program without a companion crop as well as alfalfa does.

Red clover has more shade tolerance at the seedling stage; therefore, red clover is recommended instead of alfalfa for most pasture renovation mixtures where shading by existing grasses occurs. The shade tolerance of red clover enables it to establish well in companion crops such as spring oats and winter wheat.

There are fewer varieties of red clover than of alfalfa. Private breeders are active in developing more.

Fewer acres are dedicated to mammoth red clover because its yields have been lower than most of the improved varieties of medium red clover.

Ladino clover is an important legume in pastures, but it is a short-lived species. The very leafy nature of ladino makes it an excellent legume for swine pastures. It is also a very high quality forage for ruminant animals, but problems of bloat are frequent.

Ladino lacks drought tolerance because its root system is shallower than that of red clover or alfalfa.

Kura clover is a perennial clover with rhizomatous rooting. Kura clover seedlings develop slowly, and general growth is less vigorous than red clover. The rhizomatous rooting may enable this species to be a useful pasture legume. This clover requires a special Rhizobium inoculum to enable it to fix nitrogen. Kura clover, a nonpubescent, is attacked by the potato leafhopper, whereas most pubescent clovers are not. Evaluations of the species are in progress.

Birdsfoot trefoil has been popular in permanent pastures in northern Illinois. It has a long life but becomes established very slowly. Seedling growth rate is much slower than that of alfalfa or red clover.

A root rot has made birdsfoot trefoil a short-lived crop throughout southern Illinois. The variety Dawn may have adequate resistance to persist throughout the state.

Rooting depth of birdsfoot trefoil is shallower than that of alfalfa, thus birdsfoot trefoil is not as productive during drought.

Crownvetch is well known for protecting very erodible soil areas. As a forage crop, crownvetch is much slower than alfalfa or red clover in seedling emergence, seedling growth rate, early-season growth, and recovery growth. Growth rate is similar to that of birdsfoot trefoil. The potential of crownvetch as a hay or pasture plant seems restricted to very rough sites and soils of low productivity. Crownvetch does not tolerate defoliation (grazing or hay harvesting) as well as alfalfa, red clover, or birdsfoot trefoil.

Cicer milkvetch is a perennial legume adapted to the western United States. The varieties of the species that have been evaluated in Illinois have been winter-hardy and moderate in seedling vigor and seedling growth rate, similar to birdsfoot trefoil. Its productivity appears to be less than birdsfoot trefoil's and similar or slightly greater than kura clover's. Cicer milkvetch may have a place in some pastures of Illinois as a drought-resistant and winter-hardy legume. A special Rhizobium inoculum is needed for symbiotic nitrogen fixation.

Sainfoin is a legume that was introduced into the western United States from Russia. In Illinois tests, this species has failed to become established well enough to allow valid comparisons with alfalfa, red clover, and others. Observations indicate that sainfoin has a slow growth and recovery growth rate and is not well suited to the humid conditions in Illinois.

Hairy vetch is a winter annual legume that has limited value as a hay or pasture species. Low production and its vinelike nature have discouraged much use. Hairy vetch may reseed itself and become a

weedy species in small-grain fields. Hairy vetch seeded with winter wheat at 22 to 25 pounds per acre has increased the protein yield of wheat-vetch silage. Hairy vetch is a popular cover crop, providing approximately 60 pounds of available nitrogen to a following crop. Hairy vetch should be seeded in September and not killed until mid-May to obtain high nitrogen contributions.

Lespedeza is a popular annual legume in the southern third of Illinois. It flourishes in midsummer when most other forage plants are at low levels of productivity. It survives on soils of low productivity and is low yielding. Even in midsummer, it does not produce as well as a good stand of alfalfa, nor will it encroach on a good alfalfa stand. As alfalfa or other vigorous pasture plants fade out of a pasture, lespedeza may enter.

Inoculation

Legumes—such as alfalfa, red clover, kura clover, crownvetch, cicer milkvetch, hairy vetch, ladino, and birdsfoot trefoil—can meet their nitrogen needs from the soil atmosphere if the roots of the legume have the correct Rhizobium species and favorable conditions of soil pH, drainage, and temperature. Rhizobium bacteria are numerous in most soils; however, the species needed by a particular legume species may be lacking.

There are seven general groups and some other specific strains of Rhizobium, with each group specifically infecting roots of plants within its corresponding legume group and some specific strains infecting only a single legume species. The legume groups are (1) alfalfa and sweet clover; (2) true clovers (such as red, ladino, white, and alsike); (3) peas and vetch (such as field pea, garden pea, and hairy vetch); (4) beans (such as garden and pinto); (5) cowpeas and lespedeza; (6) soybeans; and (7) lupines. Some of the individual Rhizobium strains are specific to (1) birdsfoot trefoil, (2) crownvetch, (3) cicer milkvetch, (4) kura clover, or (5) sainfoin.

Grasses

Cool-Season Perennials

Timothy is a popular hay and pasture grass in Illinois, although it is not as high yielding and has less midsummer production than smooth bromegrass or orchardgrass. A cool-season species, it is best suited to the northern half of Illinois. Variety choice is limited. There are few active timothy breeding programs in the United States.

Smooth bromegrass is probably the most widely adapted high-yielding grass species for northern and central Illinois. Smooth bromegrass combines well with alfalfa or red clover. It is productive but has limited summer production when moisture is lacking and temperatures are high. It produces well in spring and fall and can use high-fertility programs. There are several improved varieties, and breeding work continues.

Orchardgrass is one of the most valuable grasses used for hay and pasture in Illinois. It is adapted throughout the state, being marginally winter-hardy for the northern quarter of the state. Orchardgrass heads out relatively early in the spring and thus should be combined with alfalfa varieties that flower early. One of the more productive grasses in midsummer, it is a high-yielding species and several varieties are available.

Reed canarygrass is not widely used, but it has growth attributes that deserve consideration. Reed canarygrass is the most productive of the tall, cool-season perennial grasses that are well suited to Illinois hay and pasture lands. Tolerant of wet soils, it also is one of the most drought-resistant grasses and can use high fertility. It is coarser than orchardgrass and smooth bromegrass and can be as coarse as tall fescue when mature. Grazing studies indicate that, under proper management, reed canarygrass can produce good weight gains on cattle equal to those produced by smooth bromegrass, orchardgrass, or tall fescue. Reed canarygrass should be considered for grazing during spring, summer, and early fall. Cool temperatures and frost retard growth and induce dormancy earlier than in tall fescue, smooth bromegrass, or orchardgrass. New low-alkaloid varieties have improved animal performance.

Tall fescue is a high-yielding grass. It is outstanding in performance when used properly and is a popular grass for beef cattle in southern Illinois. Because it grows well in cool weather, tall fescue is especially useful for winter pasture, and it is also most palatable during the cool seasons of spring and late fall. A fungus living within the plant tissue (endophyte) has a major influence on the lower palatability and digestibility of this grass during the warm summer months. Varieties are available that are fungus-free or low in fungus. Tall fescue is marginally winter-hardy when used in pastures or hay crops in the northern quarter of the state.

Rescuegrass, variety Matua, has been introduced to Illinois markets in recent years from New Zealand. Matua establishes well but is only moderately winter-hardy, suffering injury during severe winters.

Warm-Season Annuals

Sudangrass, sudangrass hybrids, and sorghum-sudangrass hybrids are annual grasses that are very productive during the summer. These grasses must be

seeded each year on a prepared seedbed. Although the total-season production from these grasses may be less than that from perennial grasses with equal fertility and management, these annual grasses fill a need for quick, supplemental pastures or green feed. These tall, juicy grasses are difficult to make into high-quality hay. Sudangrass and sudangrass hybrids have finer stems than the sorghum-sudan hybrids and thus will dry more rapidly; they should be chosen for hay over the sorghum-sudan hybrids. Crushing the stems with a hay conditioner will help speed drying. These crops may be used for silage, green chop, or pasture more effectively than for hay.

Sudangrass, sudangrass hybrids, and sorghum-sudangrass hybrids produce prussic acid, a compound that is toxic to livestock. Prussic acid is the common name for hydrogen cyanide (HCN). The compound in sorghum plants that produces HCN is dhurrin. Two enzymes are required to hydrolyze dhurrin to HCN. The microflora in the rumen of ruminant animals are capable of enzymatic breakdown of dhurrin, producing HCN. The concentration of dhurrin is highest in young tissue, with more found in leaves than in stems. There is more dhurrin in the forage of grain or forage sorghums than in sorghum-sudangrass hybrids, and more in sorghum-sudangrass hybrids than in sudangrass hybrids or sudangrass.

Sudangrass and sudangrass hybrids are considered safe for grazing when they are 18 inches tall. Sorghum-sudangrass hybrids should be 24 inches tall before grazing is permitted. Very hungry cattle or sheep should be fed other feeds that are low in prussic-acid potential before turning them onto a lush sudangrass or sorghum-sudangrass pasture. This prefeeding will prevent rapid grazing and a sudden influx of forage that contains prussic acid. These animals can tolerate low levels of prussic acid because they can metabolize and excrete the HCN.

Frost on the crops of the sorghum family breaks cell walls and permits the plant enzymes to come into contact with dhurrin and HCN to be released rapidly. For this reason, it is advisable to remove grazing ruminant livestock from freshly frosted sudangrasses and sorghums. When the frosted plant material is thoroughly dry, usually after 3 to 5 days, grazing can resume. Grazing after this time should be observed closely for new tiller growth, which is high in dhurrin; and livestock should be removed when there is new tiller growth that is being grazed.

The sorghums can be ensiled. The fermentation of ensiling reduces the prussic acid potential substantially. This method is the safest for using feed that has a questionably high prussic acid potential.

Harvesting these crops as hay is also a safe way of using a crop with questionably high levels of prussic-acid potential.

Toxic levels of prussic acid (HCN) vary. Some workers report toxicity at 200 ppm HCN of tissue dry weight, while others report moderate toxicity at 500 to 750 ppm HCN of tissue dry weight. Laboratory diagnostic procedures can determine relative HCN potential. An alkaline picrate solution is commonly used to detect HCN in plant tissue.

Millets are warm-season annual grasses that are drought tolerant. Four commonly known millets are pearlmillet (*Pennisetum typhoides* [Burm.] Stapf & C.E. Hubb.), browntop millet (*Panicum ramosum* L.), foxtail or Italian millet (*Setaria italica* [L.] Beav.), and Japanese millet (*Echinochloa crusgalli* var. *frumentacea* [Roxb.] W.F. Wight). Pearlmillet has been evaluated in grazing trials and is a suitable alternative for summer annual pastures.

Pearlmillet requires a warmer soil for rapid establishment than does sudangrass. Seedings should be delayed until the seedbed averages 70°F.

Pearlmillet does not have a prussic-acid potential as does sudangrass, nor is pearlmillet as susceptible to leaf diseases. Pearlmillet is more drought tolerant than is sudangrass, thus producing more pasture during the hot, dry periods of late summer.

Forage Mixtures

Mixtures (Table 8.01) of legumes and grasses usually are desirable. Yields tend to be greater than with either alone. Grasses are desirable additions to legume seedings to fill in where the legume ceases to grow, to reduce soil erosion, to increase the drying rate, to reduce legume bloat, and perhaps to improve animal acceptance. Mixtures of two or three well-chosen species usually yield more than mixtures that contain five or six species, some of which are not particularly well suited to the soil, climate, or use.

Warm-Season Perennials

Warm-season perennial grasses also are known as native prairie grasses. These prairie grasses normally provide ample quantities of fair- to good-quality pasture during midsummer when cool-season perennials are low yielding and often of low quality. Switchgrass, big bluestem, and indiangrass have been the more popular prairie grasses for use in Illinois.

Switchgrass (*Panicum virgatum* L.) is a tall, coarse-stemmed grass with long, broad leaves that grows 3 to 5 feet tall, with short rhizomes. It is not as palatable as smooth bromegrass. It is native to the Great Plains.

In Illinois, switchgrass starts growing in May but makes most of its growth in June to August. Switchgrass is one of the earliest maturing prairie grasses. Grazing or harvesting should leave a minimum of a 4- to 6-inch stubble. Close grazing or harvesting quickly diminishes the stand.

Switchgrass needs abundant moisture and fertility for maximum growth. Because switchgrass is tolerant of moist soils, it is often used in grass waterways.

Varieties. Blackwell, Caddo, Kanlow, Nebraska 28, Pathfinder, and Trailblazer were selected in the southern and central Great Plains. Trailblazer, released in 1985, is more digestible than the other varieties. Cave-in-Rock was selected from southern Illinois in 1958 and released by the Soil Conservation Service, Elsberry, Missouri, in 1972. Cave-in-Rock has yielded well in Illinois trials.

Switchgrass should be seeded in mid-April to early May. A continuous supply of soil moisture is needed for germination and early seedling development. Precipitation during the first 10 days following seeding has been more important for the establishment of switchgrass than the seeding date.

A seeding rate of 6 pounds of pure live seed (PLS) per acre of switchgrass is adequate if weeds are controlled and precipitation is favorable. Increasing the seeding rate increases the number of seedlings established but has little effect on forage yield or forage quality of established stands.

Frequent grazing or hay harvesting—more often than every 6 weeks—reduces the yield and vigor of switchgrass. A harvest may be taken after frost without reducing yield and vigor the following year.

Crude protein and digestible dry matter of switchgrass decline with maturity. Animal gains on switchgrass may be less than on big bluestem or indiangrass.

Switchgrass, indiangrass, and big bluestem yield well as pasture plants. A major portion of the growth occurs after July 1, and nearly all growth from these grasses is completed by August 1 in southern Illinois. The dry-matter yield of switchgrass is greater than that of indiangrass and big bluestem.

The crude protein content of switchgrass is higher than indiangrass or big bluestem at comparable maturities during the pasture season. The crude protein values range from 3.4 to 6.4 percent for the major yield of the season. These values are very low if these forages are the only protein source for cattle, sheep, or horses. Big bluestem tends to have a higher crude protein content than indiangrass.

The digestible dry matter of warm-season perennial grasses tends to be below 50 percent. This level is below the maintenance level for pregnant beef cows, which may need supplemental feed when pasturing on switchgrass. Indiangrass and big bluestem tend to be a little higher in digestibility than switchgrass, but they are marginal for maintenance of pregnant beef cows. Dry-matter digestibility may be underestimated by in vitro analysis methods.

Warm-season perennial grasses may yield 5.5 to 7.5 tons of hay dry matter per acre throughout Illinois.

Big bluestem (*Andropogon gerardii* Vitman) grows 4 to 7 feet tall and is a sod-forming, warm-season perennial grass. It was a major contributor to the development of the deep, dark, prairie soils of Illinois. This perennial has short rhizomes, but it makes a very tough sod. Big bluestem thrives on moist, well-drained loam soils of relatively high fertility. It is one of the dominant grasses of the eastern Great Plains and is found in association with little bluestem, switchgrass, and indiangrass. Big bluestem establishes slowly from seed.

Big bluestem begins growth in May and makes a large part of its growth in late July through August. Grazing should leave a 6-inch stubble to prevent loss of stand.

This grass is palatable and nutritious in its early stages of growth. It withstands close grazing late in the season if it is protected from close grazing early in the season. Good hay may be made if harvested before seed heads emerge. Seed matures in late September and October.

Roundtree big bluestem was released by the Soil Conservation Service and the Missouri Agricultural Experiment Station in 1983. Other varieties of big bluestem are Champ, Kaw, and Pawnee. Other bluestem varieties include Plains (Yellow Bluestem), released by the Oklahoma Agricultural Experiment Station in 1970, and King Ranch.

Seedings should be made from mid-May to mid-June at 10 pounds of PLS per acre. Seed at ¼ inch deep, on a prepared seedbed that has been firmed with a corrugated roller. Use no nitrogen during the seeding year. See Table 8.02 for yield information.

Indiangrass (*Sorghastrum nutans* [L.] Nash) is a sod-forming grass with a deep, extensive root system with short rhizomes. It is adapted to deep, well-drained soils.

Indiangrass produces fair- to good-quality forage during the summer months. Grazing months are July through mid-September. Harvest indiangrass for hay at the early boot stage. Begin grazing after the plant reaches 18 inches. Graze to a minimum of a 10-inch stubble.

Varieties are Holt, from the Nebraska Agricultural Experiment Station; Osage, from the Kansas Agricultural Experiment Station; Oto, from the Nebraska

Table 8.01. Forage Seed Mixture Recommendations in Pounds Per Acre

For hay crops

Northern, Central Illinois		Southern Illinois	
Moderately to well-drained soils			
Alfalfa	12	Alfalfa Orchardgrass	8 4
Alfalfa Smooth bromegrass	8 6	Alfalfa Tall fescue	8 6
Alfalfa Smooth bromegrass Timothy	8 4 2		
Alfalfa Timothy	8 4		
Poorly drained soils			
Red clover Timothy	8 4	Red clover Smooth bromegrass	8 6
Red clover Smooth bromegrass	8 6	Red clover Alsike clover Reed canarygrass	2 2 8
Alsike clover Timothy	5 4	Red clover Alsike clover Tall fescue	2 2 6
Alsike clover Reed canarygrass	3 8	Red clover Alsike clover Redtop	2 4 4
Birdsfoot trefoil Timothy	5 2		
Droughty soils			
Alfalfa Smooth bromegrass	8 6	Alfalfa Orchardgrass	8 4
Alfalfa Tall fescue[a]	8 6	Alfalfa Tall fescue	8 6
		Alfalfa Smooth bromegrass	8 6

For pasture renovation

Northern, Central Illinois		Southern Illinois	
Moderately to well-drained soils			
Alfalfa Red clover	8 4	Alfalfa Red clover	8 4
Poorly drained soils			
Birdsfoot trefoil Red clover	4 4	Red clover Ladino clover Alsike clover	4 ½ 2

For rotation and permanent pastures

Northern, Central Illinois		Southern Illinois	
Moderately to well-drained soils			
Alfalfa Smooth bromegrass Timothy	8 5 2	Alfalfa Orchardgrass	8 4
Alfalfa Orchardgrass[a]	8 4	Alfalfa Tall fescue	8 6
Alfalfa Orchardgrass[a] Timothy	8 4 2	Ladino clover Tall fescue	½ 8
Red clover Ladino clover Orchardgrass[a]	8 ½ 4	Alfalfa Smooth bromegrass Timothy	8 6 2
Red clover Ladino clover Tall fescue	8 ½ 6–8	Ladino clover Orchardgrass[a]	½ 6
Ladino clover Orchardgrass[a]	½ 6	Red clover Ladino clover Orchardgrass	8 ½ 4
Birdsfoot trefoil Timothy	5 2	Red clover Ladino clover Tall fescue	8 ½ 6–8
Ladino clover Smooth bromegrass	½ 8	Orchardgrass Tall fescue	8 10
Orchardgrass[a] Tall fescue[a]	8 10		
Poorly drained soils			
Alsike clover Ladino clover Timothy	3 ½ 4	Alsike clover Ladino clover Tall fescue	2 ½ 8
Birdsfoot trefoil Timothy	5 2	Alsike clover Ladino clover Reed canarygrass	3 ½ 8
Alsike clover Ladino clover Reed canarygrass	3 ½ 8		
Alsike clover Ladino clover Tall fescue	2 ½ 8		
Droughty soils			
Northern, Central Illinois		**Southern Illinois**	
Alfalfa Smooth bromegrass	8 5	Alfalfa Orchardgrass	8 4

Table 8.01. Forage Seed Mixture Recommendations in Pounds Per Acre (cont.)

FOR ROTATION AND PERMANENT PASTURES (CONT.)

Droughty soils (cont.)

Northern, Central Illinois		Southern Illinois	
Alfalfa	8	Alfalfa	8
Orchardgrass[a]	4	Tall fescue	6
Alfalfa	8	Alfalfa	6
Tall fescue	6	Red clover	3
		Orchardgrass[a]	4
Red clover	8	Alfalfa	6
Orchardgrass[a]	4	Red clover	3
Red clover	8	Tall fescue	6–8
Tall fescue	6–8		

FOR WARM-SEASON PERENNIAL GRASSES

Moderately to well-drained and droughty soils,[b] anywhere in Illinois

Single species		*Mixtures*	
Switchgrass	6	Big bluestem	5
Eastern gamagrass	12	Indiangrass	5
Big bluestem	10	Switchgrass	2
Caucasian bluestem	3	Big bluestem	4
Indiangrass	10	Indiangrass	4

FOR HORSE PASTURES

Northern, Central Illinois		Southern Illinois	
Moderately to well-drained soils			
Alfalfa	8	Alfalfa	8
Smooth bromegrass	6	Orchardgrass	3
Kentucky bluegrass	2	Kentucky bluegrass	5
Alfalfa	8	Alfalfa	8
Orchardgrass[a]	3	Smooth bromegrass	6
Kentucky bluegrass	5	Kentucky bluegrass	2
Alfalfa	5	Alfalfa	5
Red clover	4	Red clover	4
Orchardgrass[a]	3	Orchardgrass	3
Kentucky bluegrass	5	Kentucky bluegrass	5
Poorly drained to somewhat poorly drained soils			
Red clover	8	Red clover	8
Smooth bromegrass	6	Orchardgrass	6
Kentucky bluegrass	2	Kentucky bluegrass	5
Timothy	2		
Alfalfa	5	Ladino clover	½
Red clover	4	Orchardgrass	6
Smooth bromegrass	6	Kentucky bluegrass	5
Kentucky bluegrass	2		

FOR HOG PASTURES

All soil types, anywhere in Illinois

Alfalfa	8
Ladino clover	2

[a]Central Illinois only.
[b]Not recommended for poorly drained soils.

Agricultural Experiment Station; and Rumsey, from a native stand in south-central Illinois.

Seedings should be made from mid-May to mid-June at 10 pounds of PLS per acre. Seed at ¼ inch deep, on a prepared seedbed that has been firmed with a corrugated roller. Use no nitrogen during the seeding year. See Table 8.02 for yield information.

Eastern gamagrass (*Tripsacum dactyloides* [L.] L.) is related to corn. The seed heads have the female flowers on the lower portion and the male flowers above. It grows in large clumps in low areas, is quite palatable, and often is destroyed by close grazing. Eastern gamagrass produces a large tonnage of forage and can be used for hay or silage.

Seedings should be made from mid-May to mid-June at 12 pounds of PLS per acre. Seed at ¼ inch deep, on a prepared seedbed that has been firmed with a corrugated roller. Use no nitrogen during the seeding year. See Table 8.02 for yield information.

Caucasian bluestem or old world bluestems (*Bothriochloa caucasica* C.E. Hubb.), a perennial bunchgrass, is an introduction from Russia that shows promise as a pasture and hay grass in Illinois. It is easily established from seed and makes good growth even if moisture supplies are low. It bears an abundance of small, viable seed that shatter readily.

Seedings should be made from mid-May to mid-June at 3 pounds of PLS per acre. Seed at ¼ inch deep,

Table 8.02. Species and Varieties of Warm-Season Perennial Grasses at Dixon Springs

Species/variety[a]	2-year average dry matter, tons per acre
Switchgrass/Cave-in-Rock	5.47
Eastern gamagrass/Pete	7.20
Big bluestem/Roundtree	4.84
Caucasian bluestem	3.58
Indiangrass/Rumsey	6.03

[a]Each variety is harvested twice a year.

on a prepared seedbed that has been firmed with a corrugated roller. Use no nitrogen during the seeding year. See Table 8.02 for yield information.

Establishment of Warm-Season Perennial Grasses

Establishment of warm-season perennial grasses is slow. Seedings need to be made early in the season, from April through June, to allow adequate time for the seedlings to establish well. Atrazine (at 2 pounds of active ingredients per acre) may be applied to the surface after seeding big bluestem. Switchgrass and indiangrass seedlings are damaged by atrazine.

Suggested seeding rates are 6 pounds of PLS per acre of switchgrass and 10 pounds of PLS per acre of big bluestem and indiangrass. Do not graze until plants are well established, at least 1 year old. Weeds may be reduced during the seeding year by clipping. The first clipping should occur about 60 days after seeding, at a height of 3 inches. Later clippings should be at no less than 6-inch stubble height. Do not clip after August 1.

Seedings should be made on prepared seedbeds that are very firm. The drill or seeder must be able to handle the seed, because seeds of indiangrass and big bluestem are light and feathery. Debearding will help to get the seed through the seeders.

Seedings may be made into existing grass sods, but the grass must be destroyed. Roundup will remove most grasses, when applied according to label instructions. Atrazine also may be used for seeding big bluestem into a grass sod. A no-till drill is needed to place seeds into soil surface for good soil-seed contact.

Fertilization

Warm-season perennial grasses prefer fertile soils but grow well in moderate fertility conditions. Warm-season perennials do not respond to nitrogen fertilization as much as cool-season perennials. Warm-season perennial grasses use minerals and moisture more efficiently than cool-season perennial grasses.

For establishment, fertilize with 30 to 40 pounds of nitrogen, 24 to 30 pounds of phosphate, and 40 to 60 pounds of potash per acre.

For pasture or hay production of established stands, fertilize with 100 to 120 pounds of nitrogen, 50 to 60 pounds of phosphate, and 100 to 120 pounds of potash per acre.

Corn Silage

Corn silage is an important crop on many Illinois livestock farms. Several of the cultural practices are the same as corn grown for grain and thus are discussed in Chapters 2 and 11.

In selecting hybrids for corn silage, consider grain yield, whole plant silage yield, relative maturity, standability, pest resistance, and silage quality.

Additional Information

Additional information can be found in the North Central Regional (NCR) Extension publication NCR 547, *Alfalfa Management Guide*, which is available at Extension offices.

Author

James A. Morrison
Extension Educator, Crop Systems
Rockford Extension Center

Chapter 9. Seed

Seed production is not only the basis of a large industry in Illinois; it is also a vital part of all crop production in the state. It has appropriately been said that all successful crop production begins with good seed.

Seed represents both the product of grain crop production and the beginning of the next life cycle of the crop. A seed contains, in a fairly small package, a tiny plant with embryonic roots, stem, and leaves; a food supply that provides energy, fats, and proteins needed to support the growth of the seedling during germination; and a seed coat to help protect the contents from insects and diseases.

Seed Quality and Storage

Genetic purity and good seed quality are the major goals of most seed producers. Genetic purity begins with careful selection for plant uniformity by breeders and removal of off-type plants during early seed generations, and is then maintained by careful sanitation —cleaning of equipment and storage structures—as succeeding generations of seed are produced. Seed quality is defined by *germinability*—the percentage of seeds that will germinate to produce a new seedling, and by *vigor,* the ability of the seed to produce a healthy seedling quickly, even under conditions that are not ideal. Germinability and vigor are somewhat related, but it is possible for seed to germinate well but still not be very vigorous.

Seed quality is generally measured using one or more germination tests. The *standard warm germination* test consists of placing seeds on germination paper for a specified period of time at a specified (warm) temperature, and then counting the percentage of seeds that produce seedlings. The standard warm germination percentage is required to be put on seed tags for retail sale. Under ideal field conditions, emergence percentage in the field may be almost as high as the standard warm germination percentage.

The *cold test* consists of keeping the seed at a temperature—usually 50°F—at which germination is very slow, in the presence of unsterilized soil, and then placing the seeds and soil in warm temperatures for several days before reading emergence percentage. This test is designed to duplicate difficult (cold, wet) field conditions, and to see how seed will germinate and emerge under such conditions. It is used routinely by companies before seed is delivered for sale. The cold test is not standardized due to the difficulty in having uniform soil and soil microbes among different labs; different labs may produce different cold test results. Another type of "stress test" is the *accelerated aging* test, which measures germination after keeping the seed at high temperatures and high humidity for several days. While this does not duplicate field conditions, it accelerates the rate of deterioration of seed vigor, and hence it identifies seed that might be declining rapidly in quality, even though its initial germination percentage may still be high.

Relative changes in germinability and vigor of seed during storage are illustrated in Figure 9.01. How soon the decline in vigor and germinability begins

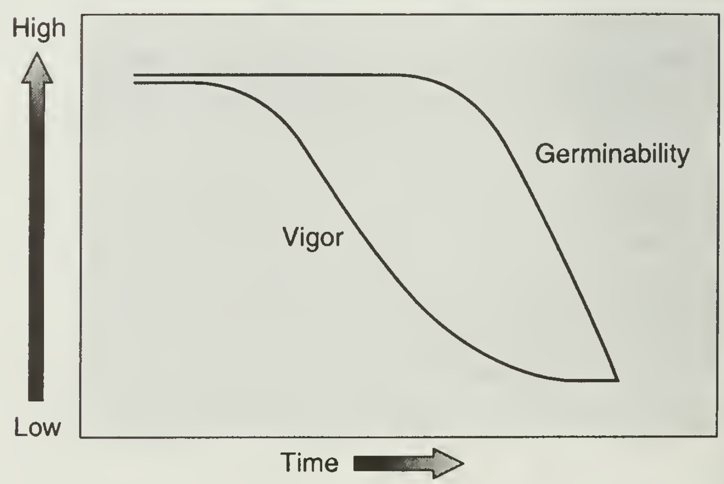


Figure 9.01. Relative changes in seed germinability and vigor during storage.

will vary with storage conditions; longer storage is possible with drier seed and lower storage temperatures. In general, seeds such as soybean that contain higher oil percentages are more difficult to store, partly due to biochemical reasons and also to the fact that such seeds may be more easily damaged by mechanical handling. Soybean seed can be stored for at least a year under normal conditions, but longer storage requires more attention to temperature and seed moisture. Seed of crops such as corn and wheat store much better than oilseeds. It is often possible to store such seeds for 3 years or more without much loss in vigor, though some refrigeration may be used in the summer.

Seed Considerations for Illinois Crops

There are different considerations pertaining to seed of different crops grown in Illinois:

1. **Corn** seed production is a major industry in Illinois. Corn seed is nearly all hybrid seed, produced by one inbred parent that was pollinated in the field by a second inbred. Corn is very well suited to this type of seed production, since it has separate male and female flowers—the tassel and ear—and it naturally cross-pollinates to a large extent. To force two plants or rows of plants to cross-pollinate, all one need do is remove the tassels of one of the parents (usually called the *female* or *seed* parent), and then let the other plant or row (the *male* or *pollinator* parent) serve as the source of pollen. Tassel removal is usually done mechanically or by hand, though there is some genetic male sterility that prevents the shedding of pollen. Genetic purity is assessed by visual inspection to see how well pollen shed has been controlled, and by growing seed in the field (in warm climates) during the winter (called *growouts*) to see if plants that grow from it are uniform. A corn hybrid is genetically uniform only in the first generation, and succeeding generations *segregate*, or produce a great deal of genetic variability. Thus seed produced from hybrid seed cannot be used as seed for another generation without a large loss in yield potential.

   Corn seed is usually harvested early to prevent it from being injured by frost. It is usually harvested as ears, which are then carefully dried and shelled in a way that minimizes mechanical damage. Corn seed is usually sold for retail in bags that contain 80,000 kernels (called a *unit*), with weight varying with seed size. There is also some movement toward selling in bulk containers to save costs of bagging and handling. Corn seed is usually sized mechanically (graded) in order to make it feed more uniformly through planting mechanisms. Grades are usually designated by both size and shape (e.g., "small rounds" or "medium flats"), but in practical terms grades are of importance only in how they affect uniformity of metering by planting mechanisms. Research has generally shown little or no effect of seed grade on field emergence or yielding ability.

2. **Soybean** seed is, as indicated above, somewhat more difficult to produce and maintain quality in than is corn seed. Genetic purity is maintained by field inspections, either by producing companies or by official seed certifying agencies (the Illinois Crop Improvement Association in Illinois), and by using growouts or other genetic tests. Seed companies often use special handling equipment to reduce mechanical injury to soybean seed.

   Like other self-pollinated crops, soybean "breeds true," meaning that, once genetic purity is attained by selection for uniformity, each generation is genetically identical to the previous generation. Thus the use of "bin-run" seed, which is seed produced and kept by farmers for their own use, is an issue in soybean. The Plant Variety Protection Act of 1970 restricted the commercial production and sale of protected varieties to the companies that owned or licensed such varieties, but it allowed limited sales to neighboring farmers by farmers who were not in the seed business. A modification of this law several years ago further restricted the sale of protected seed, effectively prohibiting sale of such seed to one's neighbors. Finally, recent genetic developments, such as Roundup Ready, require agreements that farmers will not keep seed even for their own use.

   Even without legal restrictions on keeping one's own seed or buying it from neighbors, the use of bin-run seed may not always be the best management choice for farmers. For example, the market price of the seed needs to be considered as part of the cost; the use of bin-run seed may slow the rate of use of newer, better varieties; lack of specialized handling and cleaning equipment may reduce seed quality; and lack of controlled germination tests may result in the use of substandard seed. Many producers prefer to buy their seed in bags or bulk from professional seed producers rather than take chances with seed that they produced themselves. Any seed kept for one's own use should be cleaned by a special seed cleaner to remove weed seeds and broken or misshapen seeds, and germination should be tested by a professional lab.

3. **Wheat and oats** seed, though they store considerably better than soybean seed and are less subject to mechanical injury, are handled, cleaned, and tested much like seed of other self-pollinated crops such as soybean. Winter wheat seed is planted only a few months after it is harvested, and so usually is of good quality if harvested on time and properly cleaned. There can be some dormancy (biochemical inability to germinate) in newly harvested winter wheat seed, but a few months of storage usually restores it to full germinability. Both wheat and oats seed are usually treated with a fungicide to reduce the incidence of seedling diseases.

4. **Forage legume** seed is produced to a very limited extent in Illinois, though some red clover, sweet clover, and hairy vetch (for cover crop) seed is produced. Such legumes usually require bees or other insects for successful pollination, though the lack of availability of beehives or other means to manage insect pollinators means that forage legume seed producers often "take what they can get" in terms of seed yield. Most often, red clover seed is produced from the second growth of the crop after the first growth is harvested for forage. Insect pollinators are also more active in mid- to late summer, thus raising yields of seed produced later in the season.

Author

Emerson D. Nafziger
Department of Crop Sciences

Chapter 10. Water Quality

The protection of water quality is an important part of any crop production system. Illinois farmers have a great stake in protecting drinking water quality because they often consume the water that lies directly under their farming operation. Their domestic water wells are often near agricultural operations or fields and thus must be safeguarded against contamination. The majority of crop protection chemicals never reach groundwater. In Illinois, favorable soil and geologic conditions help degrade or retard movement of pesticides. However, vulnerable site conditions are found in some parts of Illinois. In these areas (described in detail later) appropriate chemical selection and management decisions need to be made to ensure good water quality.

Drinking-Water Standards

New federal drinking-water standards for 18 pesticides and pesticide breakdown products went into effect on July 30, 1992. This regulation requires that public water supplies be monitored for these compounds at least four times annually. The most commonly used herbicides on the list are atrazine and alachlor. Many other commonly used herbicides are currently unregulated but will be monitored in the drinking-water samples. Currently, only surface-water supplies (lakes, reservoirs) are monitored, and groundwater sources will be phased in over the next 3 years.

Compliance with the federal standards is based on the average of the samples taken consecutively over a 1-year period. For example, atrazine has a standard of 3 parts per billion (ppb), so if the sum of four quarterly samples is equal to 12 ppb or more, the water is out of compliance. A single detection of over 12 ppb would therefore immediately put a water supply out of compliance.

If standards are exceeded, water customers are notified by local media and subsequently on their water bill. If a water source is in violation, water blending with an uncontaminated supply or extensive decontamination treatment is required. The additional water-treatment expense can be prohibitive to small communities; this underlines the importance of agriculture-management practices that reduce the entry of herbicides into the aquatic system.

Illinois Water-Quality Results

The Illinois Environmental Protection Agency analyzed finished drinking water at 129 surface-water supplies in 1991 and 1992. The study provides a look at the potential for noncompliant water supplies in the coming years (Table 10.01). About 13 percent of the surface water samples exceeded the 3-ppb drinking-water standard for atrazine. Detections of atrazine exceeded 50 percent for both years of the study. The drop in detections in 1992 may be related to a drier spring that resulted in less cropland runoff directly following herbicide application. Trifluralin is a herbicide that is tightly held to soil particles. Trifluralin's

Table 10.01. Herbicide Detections in Selected Community Water Supplies in Illinois

Pesticide	Percent supply detections 1991	Percent supply detections 1992	Maximum concentration	Minimum concentration detected	Percent exceeding maximum contaminant level (MCL)
			--------*ug/1*--------		
Atrazine	78	55	13.0	.03	13
Alachlor	52	17	2.0	.02	< 1
Metolachlor	49	30	30.0	.02	
Trifluralin	23	5	0.36	.02	
Cyanazine	11	38	16.0	.06	

SOURCE: Illinois EPA.

presence in 23 percent of the samples in 1991 suggests that erosion of soil with attached herbicide may be responsible for some of the detections.

A statewide study of rural private water supplies involving 337 wells was conducted cooperatively by the Illinois Department of Agriculture, the U of I Cooperative Extension Service, and the state Geological Survey. The study was completed in 1992 (Table 10.02). Results of the study offer the first statistically valid estimate of the condition of well water in Illinois. About 12 percent of the 360,000 rural private wells in the state contained detectable concentrations of at least one herbicide, and 10.5 percent of the wells had nitrate nitrogen above the drinking-water standard of 10 ppm. Preliminary interpretation of the data suggests that shallow wells and dug wells were more likely to be contaminated than deep-drilled wells. Wells drawing water from aquifers within 20 feet of land surface were more likely to contain high levels of nitrate. The 2.1 percent of wells containing pesticide concentrations above the drinking-water standards were fully accounted for by three compounds: alachlor (Lasso), dieldrin (a pesticide whose registration has been canceled), and heptachlor epoxide (a degradation product of a discontinued insecticide).

No interpretation of contamination source is possible with this study, so it is impossible to determine whether the compounds originated from a point source (spill) or a nonpoint source (leached into water from regular farm practices). Pesticides detected in greater than 1 percent of the wells include acifluorfen (1.4 percent, Blazer), atrazine (2.1 percent, AAtrex); bentazon (1.4 percent, Basagran); dieldrin (1.6 percent); dinoseb (3.7 percent, Dyanap); and prometon (1.2 percent, Pramitol). The following pesticides were detected in 0.1 to 1.0 percent of the wells: alachlor (0.7 percent, Lasso); aldrin (0.3 percent); bromacil (0.3 percent, Hyvar-X); chloramben (0.2 percent, Amiben); 2,4-D (0.1 percent); endrin (0.8 percent); metolachlor (0.3 percent, Dual); metribuzin (0.1 percent, Lexone, Sencor); simazine (0.2 percent, Princep); and trifluralin (1.0 percent, Treflan). Atrazine was not found in any well at concentrations above the drinking-water standard of 3 ppb. Additionally, 19 of the pesticides (or their breakdown products) were not detected in any of the wells. These include butylate (Sutan+); cyanazine (Bladex); 2,4-DB; dicamba (Banvel); and EPTC (Eptam).

Table 10.02. Statewide Estimates for Percent and Number of Rural, Private Wells Containing Pesticides and Nitrate

	Estimated percentage of wells	Confidence interval	Estimated number of wells in Illinois
Pesticides	12.1	7.5 to 16.7	43,600
Pesticides (MCL/HAL)	2.1	0.6 to 3.6	7,560
Nitrate nitrogen (> 10 ppm)	10.5	6.7 to 14.3	37,800

NOTE: MCL = maximum contaminant level; HAL = health advisory level; ppm = parts per million.

Results from surface- and well-water samples suggest that atrazine is the most likely herbicide to appear in surface water but does not appear to be widely found in well water at levels above drinking-water standards. Alachlor and several discontinued insecticides are the predominant organic pesticide contaminants in rural well water. Nitrate nitrogen contamination is often associated with shallow wells and surface water and may be an indication of movement of fertilizers, manures, and other wastes into these water supplies. The greatest challenge facing Illinois producers may be to keep herbicides out of the surface-water supplies. Management practices that reduce runoff may help in this regard.

In other studies, the highest levels of detection are often from wells near chemical handling sites, or wells known to have been contaminated directly by an accidental point-source introduction of the chemical, such as back-siphoning.

Protection of groundwater drinking sources is a critical and achievable task that can be accomplished by (1) preventing point source contamination of the well; (2) evaluating the groundwater contamination susceptibility as determined by soil and geologic conditions and the water-management system; (3) selecting appropriate chemicals and chemical application strategies; and (4) practicing sound agronomy that uses integrated pest management principles and appropriate yield goals.

Drinking-Water Contaminants

Many substances in the environment, whether related to industry or agriculture or of natural derivation, have been associated with health problems in humans and livestock. The scope of this chapter does not warrant a full discussion of all pollutants but rather focuses on the contaminants that are associated with agriculture and the rural farmer. The most frequent contaminant of rural wells is coliform bacteria, which are associated with livestock or human waste. These bacteria enter wells laterally through a septic tank

leach field or over land into a wellhead as runoff from livestock impoundments. Nitrate-nitrogen is the second most common substance that occurs in levels exceeding health advisories. Although the presence of nitrates (NO_3) in drinking water is frequently blamed on agriculture, nitrates come from many sources, including septic tanks, livestock waste, and decaying organic matter. Bacteria and nitrates are often the "first to arrive" in a well with high potential for contamination. Together their presence suggests a possible pathway to the well from an established contaminating source.

A variety of herbicides were detected in trace amounts in potable water supplies. A recently completed nationwide survey found detectable levels of herbicides in 13 percent of the wells surveyed. Atrazine, detected in 12 percent of the wells surveyed, constituted more than 90 percent of the total detections. Although the herbicides were detected in a significant percentage of the wells, only 0.11 percent of the wells had herbicide concentrations above the health-advisory levels.

Point-Source Prevention

Control of point-source contamination is a farmer's most important action in protecting a groundwater drinking source. A point source is a well-defined and traceable source of contamination such as a leaking pesticide container, a pesticide spill, or back-siphoning from spray tanks directly into a well. Because point sources involve high concentrations or direct movement of contaminants to the water source, the purifying ability of the soil is bypassed. The following handling practices, based largely on common sense, minimize the potential for groundwater contamination:

- Never mix chemicals near (within 200 feet of) wells, ditches, streams, or other water sources.

- Prevent back-siphoning of mixed pesticides from the spray tank to the well by always keeping the fill hose above the overflow of the spray tank.

- Store pesticides downslope from well-water sources and a safe distance from both wells and surface waters.

- Triple-rinse pesticide containers, and put rinsate back into the spray tank to make up the final spray mixture.

- Avoid introducing pesticides or fertilizers into sinkholes or abandoned wells. Lateral movement of contaminants in the groundwater to a drinking-water well may be more rapid than vertical movement through the soil.

- Seal abandoned wells to prevent connection between agricultural practices and the groundwater.

Groundwater Vulnerability

Site characteristics, including the soil and geologic properties, water table depth, and depth of the well, will determine the potential of nonpoint contamination of the groundwater. Nonpoint sources of contamination are difficult to pinpoint, originate from a variety of sources, and are affected by many processes. Contaminants moving into groundwater from routine agricultural use are an example of a nonpoint source. Producers applying pesticides in vulnerable areas should pay strict attention to chemical selection and management practices.

Soil Characteristics

Water-holding capacity, permeability, and organic-matter content are important soil properties that determine a soil's ability to detain surface-applied pesticides in the crop root zone. Fine-textured, dark prairie soils have large water-holding capacities, low permeabilities, and large organic-matter contents, all attributes that reduce pesticide leaching due to reduced water flow or increased binding of pesticides. The forest soils that dominate the landscape in western and southern Illinois are slightly lower in organic matter and thus may be less effective at binding pesticides.

The most vulnerable soils for groundwater contamination are the sandy soils that lie along the major river valleys of Illinois. Sandy soils are highly permeable, have low organic-matter contents, and often are irrigated. All of these factors represent increased risks to groundwater quality. Extra precautions in chemical selection and application method should be taken in these vulnerable soils. Irrigators in particular should pay attention to groundwater advisory warnings that restrict the use of some herbicides on sandy soils.

Geology

The geologic strata beneath a farming operation may be important in determining the risk of nonpoint contamination. In Illinois the most hazardous geology for groundwater pollution is the karst or limestone region that occurs along the margins of the Mississippi River and in the northwestern part of the state. Sinkholes and fractures that occur in the bedrock in these areas may extend to the soil surface, providing access for runoff directly to the groundwater. Water moving into these access points bypasses the natural treatment provided by percolation through soil. Karst areas should be farmed carefully with due attention to buffer zones around sinkholes to prevent runoff entry

to the groundwater. Agronomic practices that minimize runoff are effective ways to reduce the potential for pesticide movement to the groundwater.

Groundwater and Well Depths

Deep aquifers that lie under impermeable geologic formations are the most protected from contamination by surface activities. Shallow water-table aquifers are more vulnerable to contamination because of their proximity to the surface. Shallow dug wells in water-table or shallow aquifers are also more vulnerable due to typically inadequate wellhead protection.

Surface-Water Contamination

Although groundwater protection receives the majority of media attention, surface water quality is generally at greater risk. Surface waters have a greater capacity for breaking down pesticides because biological breakdown processes operate at a faster rate than in groundwater. A recent survey of surface waters in Illinois by the U.S. Geological Survey found detectable herbicide levels in 90 percent of the samples taken in May and June of 1989. Control of surface-water contamination is best achieved by controlling runoff movement of water and sediment. Soil-conservation practices and prudent use of buffer strips near stream banks generally reduce the probability of surface-water contamination.

Management Practices

Many effective management practices outlined in other sections of this handbook have been recommended with due consideration to water quality. Management is most critical in areas that are the most vulnerable to contamination.

Nutrient Management

Soil testing is a basic foundation for fertilizer recommendations. Testing manures for nutrient content allows accurate crediting for fertilizer replacement. A sound nitrogen-management program for grain crops that emphasizes appropriate yield goals and credit for prior legumes will optimize the amount of fertilizer nitrogen introduced to the field. Splitting nitrogen applications on sandy irrigated soils is wise because it reduces the chances for excessive leaching that might occur if a single nitrogen application is used.

Use of a nitrification inhibitor on fine-textured soils where nitrogen is fall applied may reduce leaching of nitrate-nitrogen. Adding nitrapyrin (N-Serve) to fall-applied nitrogen reduced nitrate leaching an average of 10 to 15 percent in a study in Minnesota. Even less nitrate leaching occurred when N was spring applied.

Integrated Pest Management

It is generally assumed that reduced pesticide use results in a reduced probability of groundwater contamination. Integrated pest management reduces unnecessary use of pesticides. Two examples are the recommended practice of crop rotation that reduces the need for corn rootworm insecticides in continuous corn and the use of crop rotation and tolerant varieties to control plant diseases.

Conservation Tillage

Reducing tillage and retaining crop residues on the soil surface limits the runoff and overland flow that carries pesticides and nutrients out of the field. The effect of conservation tillage and no-till on groundwater quality is controversial and the subject of much research. Reduction of runoff and erosion is accomplished by increasing infiltration of water. Increased infiltration, particularly through earthworm-formed macropores, offers a transport system to the subsoil that soil-applied pesticides can follow. Conversely, the macropores are not the primary routes of water flow unless heavy rainfall or flooding occurs and allows rapid movement of "clean" rainwater past the soil layers that contain pesticides. Conservation tillage methods are most important in controlling soil erosion on sloping land. Adopting more severe tillage to protect groundwater quality is not warranted based on our current knowledge.

Cover Crops

A cover crop such as a small grain or legume may provide water-quality benefits from several standpoints. The effectiveness of cover crops in controlling erosion is well documented, and controlling erosion is an important component of surface-water-quality protection. Small-grain cover crops have shown some efficiency at retrieving residual nitrogen from the soil following fertilized corn or vegetable crops. This feature may be important on sandy irrigated soils where winter rainfall leaches much of the residual nitrogen.

Legumes may provide a source of nitrogen to subsequent crops. Refer to the chapter on cover crops in this handbook for further information.

Chemical Properties and Selection

The selection of agricultural chemicals is most critical for producers on vulnerable soils and geologic sites. Herbicide selection is a complex task that must take into account the crop, the tillage system, target species, and a host of other variables. Chemical proper-

Table 10.03. Herbicide and Herbicide Premixes with Groundwater Advisories

Trade name	Common (generic) name
AAtrex, atrazine	atrazine
Basis Gold	rimsulfuron + nicosulfuron + atrazine
Bicep II, Bicep Lite II	metolachlor + atrazine + safener
Bladex/Cy-Pro	cyanazine
Broadstrike + Dual	flumetsulam + metolachlor
Broadstrike + Treflan	flumetsulam + trifluralin
Bronco	alachlor + glyphosate
Buctril + atrazine	bromoxynil + atrazine
Bullet/Lariat	alachlor + atrazine
Canopy	metribuzin + chlorimuron
Contour	imazethapyr + atrazine
Detail	imazaquin + dimethenamid
DoublePlay	acetochlor + EPTC + safener
Dual II	metolachlor + safener
Extrazine II/Cy-Pro AT	cyanazine + atrazine
Frontier	dimethenamid
Guardsman	dimethenamid + atrazine
Harness	acetochlor + safener
Harness Xtra	acetochlor + atrazine + safener
Hornet	flumetsulam + clopyralid
Laddok S-12	bentazon + atrazine
Lasso/Micro-Tech	alachlor
Marksman	dicamba + atrazine
Princep, Simazine	simazine
Scorpion III	flumetsulam + clopyralid + 2,4-D
Sencor/Lexone	metribuzin
Shotgun	atrazine + 2,4-D
Stinger	clopyralid
Surpass/TopNotch	acetochlor + safener
Surpass 100	acetochlor + atrazine + safener
Turbo	metribuzin + metolachlor

ties of the herbicide are important to consider when evaluating their potential to leach to the groundwater. The three most important characteristics of a pesticide that influence leaching potential are solubility in water, ability to bind with the soil (adsorption), and the rate at which it breaks down in the soil. High solubility (dissolves readily), low binding ability, and slow breakdown all increase a pesticide's ability to move to the groundwater. Among the frequently used herbicides that have a greater potential to leach and are labeled with groundwater advisories are those that contain alachlor, atrazine, clopyralid, cyanazine, metribuzin, metolachlor, or simazine (Table 10.03).

Precautions for Irrigators

Chemigation refers to the application of fertilizers and pesticides through an irrigation system and is a management tool that has benefits and potential drawbacks for groundwater protection. The greatest benefit of chemigation is for fertigation, which is the application of fertilizers, particularly nitrogen, through the irrigation system. Nitrogen application can be more carefully spread out in the vegetative growth period of grain crops, thereby minimizing the susceptibility of leaching.

Chemigation systems should be equipped with back-flow-prevention devices. These greatly reduce the threat of back-siphoning undiluted chemicals into the irrigation well. Back-flow-prevention devices are mandatory on irrigation systems that inject fertilizers and pesticides. Reputable irrigation dealers do not sell irrigation systems without this important feature.

Well-Water Testing

The most important step in well-water testing is to contact the local health department and determine the procedure for sampling and submitting water for nitrate and bacteria determinations. In most counties the service is provided at no cost or for a nominal fee. The presence of coliform bacteria with or without elevated nitrates is a sign that a well is contaminated by runoff or a septic system. Faulty well construction and improper wellhead protection are major causes of contamination. Pesticide testing is expensive and requires sensitive analytical equipment. Several private water-testing laboratories, certified by the Illinois Environmental Protection Agency, will perform water analyses for citizens. Contact a local Extension adviser for information on nearby laboratories.

Author

F. William Simmons
Department of Crop Sciences

Chapter 11. Soil Testing and Fertility

Soil testing is the single most important guide to the profitable application of fertilizer and lime. When soil test results are combined with information from the soil profile about the nutrients that are available to the various crops (Figures 11.13 and 11.14), the farmer has a reliable basis for planning the fertility program on each field.

Traditionally, soil testing has been used to decide how much lime and fertilizer to apply. With increased emphasis on economics and the environment, soil tests are also a logical tool to determine areas where adequate or excessive fertilization has taken place. In addition, soil tests are used to monitor the impact of past fertility practices on changes in a field's nutrient status. To accomplish this, one must (1) collect samples to the proper depth; (2) collect enough samples per unit of land area; (3) collect samples from precisely the same areas of the field that were sampled in the past; and (4) collect samples at the proper time.

Depth of sampling. The proper sampling depth for pH, phosphorus, and potassium is 7 inches. For fields in which reduced-tillage systems have been used, proper sampling depth is especially important, as these systems result in less thorough mixing of lime and fertilizer than a tillage system that includes a moldboard plow. This stratification of nutrients has not adversely affected crop yield, but misleading soil test results may be obtained if samples are not taken to the proper depth.

Under reduced-tillage systems, it is important to monitor surface soil pH by collecting samples to a depth of 2 inches from at least three areas in a 40-acre field. These areas should represent the low, intermediate, and high ground of the field. If surface soil pH is too high or too low, the efficacy of some herbicides and other chemical reactions may be affected.

Number of samples per unit of land area. The number of soil samples taken from a field is a compromise between what should be done (information) and what can be done (cost). Sampling at the rate of one composite from each 2½-acre area is suggested. (See Figure 11.01 for sampling directions.)

Field sampling studies show large differences of soil test levels in short distances in some fields. If you can use computerized spreading techniques and suspect large variations in test values over a short distance, collecting one sample from each 1.1-acre area (Figure 11.01, bottom diagram) will provide a better representation of the actual field variability. The increased sampling intensity will increase cost of the base information but allows for more complete use of technology in mapping soil fertility patterns and thus more appropriate fertilizer application rates. The most common mistake is taking too few samples to represent a field adequately. Taking shortcuts in sampling may produce unreliable results and lead to higher fertilizer costs, lower returns, or both.

Precise sample locations. Since test results may vary markedly in short distances, it is important to collect soil samples from precisely the same points each time the field is tested. This practice reduces the variation often observed between sampling times. Sample locations may be identified using global positioning system (GPS) equipment or by accurately measuring the sample points with a device such as a measuring wheel. Once locations have been identified, collect and composite five soil core samples 1 inch in diameter to a 7-inch depth from within a 10-foot radius around each point.

How to sample. A soil tube is the best implement for taking soil samples, but an auger or a spade also can be used (Figure 11.02). Five soil cores taken with a tube will give a satisfactory composite sample of about 1 to 2 cups.

When to sample. Sampling every 4 years is strongly suggested. To improve the consistency of results, samples should be collected at the same time of year. Sampling done within a few months of lime or fertilizer treatment will be more variable than after a year.

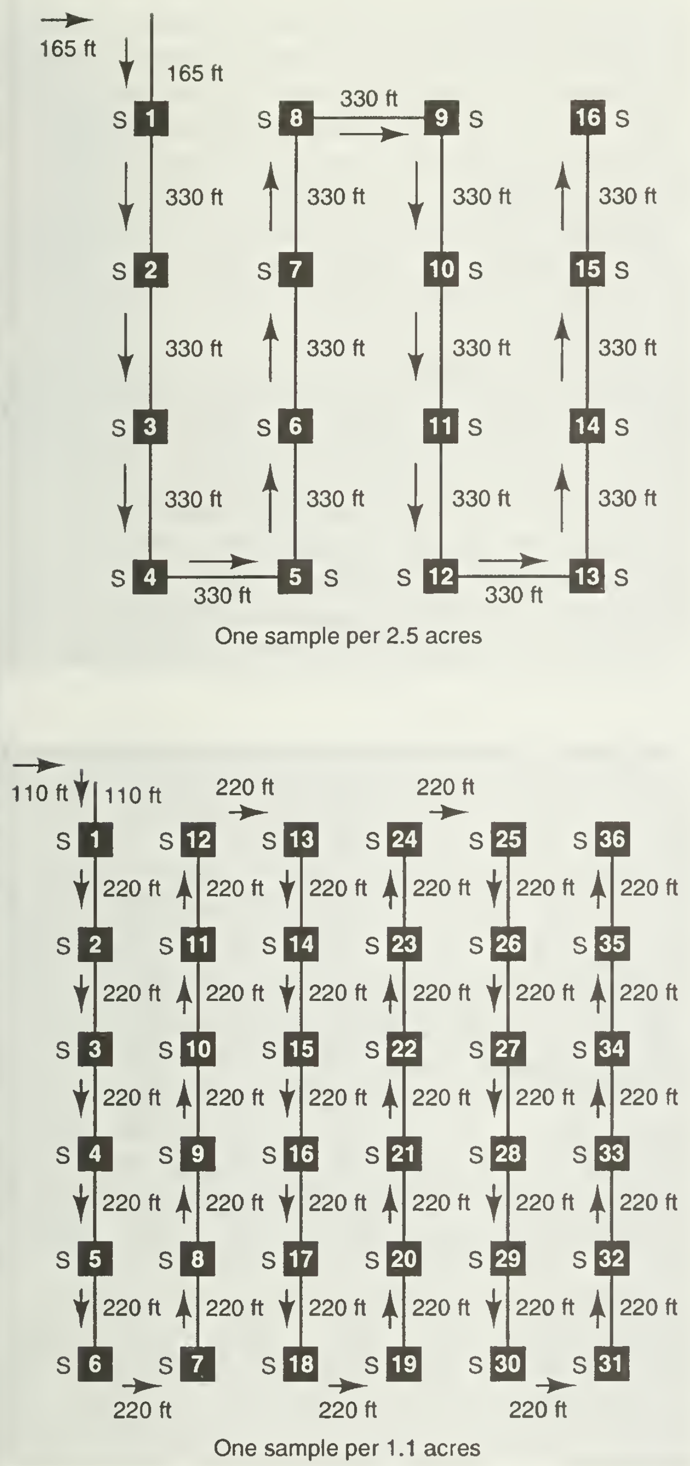


Figure 11.01. How to collect soil samples from a 40-acre field. Each sample should consist of five soil cores, 1 inch in diameter, collected to a 7-inch depth from within a 10-foot radius around each point. Higher frequency sampling (lower diagram) is suggested for those who can use computerized spreading techniques on fields suspected of having large variations in test values over short distances.

Late summer and fall are the best seasons for collecting soil samples because potassium test results are most reliable during these times. The potassium soil test tends to be cyclic, with low test levels in late summer and early fall and high test levels in late January and early February.

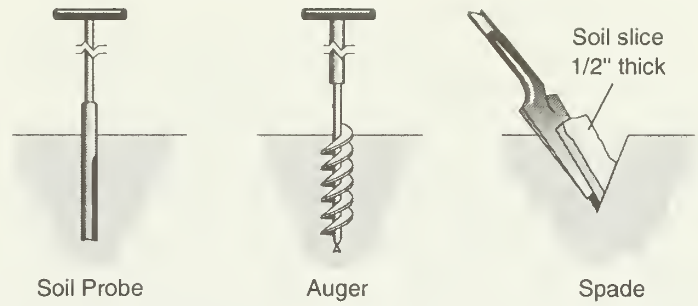


Figure 11.02. How to take soil samples with an auger, a soil probe, and a spade.

Where to have soil tested. Illinois has about 40 commercial soil-testing services. An Extension office or a fertilizer dealer can provide information about soil-testing services available in your area.

Information to accompany soil samples. The best fertilizer recommendations are based on both soil test results and a knowledge of field conditions that will affect nutrient availability. Because the person making the recommendation does not know the conditions in each field, it is important that you provide adequate information with each sample.

This information includes cropping intentions for the next 4 years; name of the soil type or, if not known, the nature of the soil (clay, silty, or sandy; light or dark color; level or hilly; eroded; well drained or wet; tiled or not; deep or shallow); fertilizer used (amount and grade); lime applied in the past 2 years; and proven yields or yield goals for all proposed crops.

What tests to have made. Soil fertility problems in Illinois are largely associated with acidity, phosphorus, potassium, and nitrogen. Recommended soil tests for making decisions about lime and fertilizer use are the water pH test, which shows soil reaction as pH units; the Bray P_1 test for plant-available soil phosphorus, which is commonly reported as pounds of phosphorus per acre (elemental basis); and the potassium (K) test, which is commonly reported as pounds of potassium per acre (elemental basis). Guidelines for interpreting these tests are included in this section. An organic-matter test made by some laboratories is particularly useful in selecting proper rates of herbicide and agricultural limestone.

Because nitrogen can change forms or be lost from soil, testing to determine nitrogen fertilizer needs for Illinois field crops is not recommended in the same sense as testing for the need for lime, phosphorus, or potassium fertilizer. Testing soil to predict the need

for nitrogen fertilizer is complicated by the fact that nitrogen availability—both the release from soil organic matter and the loss by leaching and denitrification—is regulated by unpredictable climatic conditions. Under excessively wet conditions, both soil and fertilizer nitrogen may be lost by denitrification or leaching. Under dry conditions, the amount of nitrogen released from organic matter is low, but under ideal moisture conditions, it is high. Use of the organic-matter test as a nitrogen soil test, however, may be misleading and result in underfertilization.

Scientists in Vermont and Wisconsin have identified nitrogen soil tests that work well under their conditions. Specifics of the tests, along with an evaluation of their potential and limitations for Illinois, are discussed in the nitrogen section of this chapter. Guidelines for planning nitrogen fertilizer use are also provided.

Tests are available for most secondary nutrients and micronutrients, but interpretation of these tests is less reliable than of tests for lime, phosphorus, and potassium. Complete field history and soil information are especially important in interpreting results. Even though these tests are less reliable, they may be useful in two ways:

1. *Troubleshooting* (diagnosing symptoms of abnormal growth). Paired samples representing areas of good and poor growth are needed for analyses.
2. *"Hidden-hunger checkup"* (identifying deficiencies before symptoms appear). Soil tests are of little value in indicating marginal levels of secondary nutrients and micronutrients when crop growth is apparently normal. For this purpose, plant analysis may yield more information.

Soil test ratings (given in Table 11.01) have been developed to put into perspective the reliability, usefulness, and cost-effectiveness of soil tests as a basis for planning a soil fertility and liming program for Illinois field crops. Additional research will undoubtedly improve some test ratings.

Interpretation of soil tests and formulation of soil treatment program. See page 83 for suggested pH goals and pages 105 and 107 for phosphorus and potassium information. Formulate a soil treatment program by preparing field soil test maps to observe areas of similar test levels that will benefit from similar treatment. Areas with differences in soil test pH of 0.2 unit, phosphorus test of 10, and potassium test of 30 are reasonable to designate for separate treatment.

When the soil test is variable. When there is large variation among tests on a field, the reason and, more important, what to do about it may not be obvious. *First* look at the pattern of the tests over the field. *If there is a definite pattern* of high tests in one part and low in another, check to see whether there is a difference in soil type. *Second,* try to recall whether the area was farmed as separate fields in the recent past. *Third,* check records for this field from previous tests or, if there are no records, try to remember whether portions were ever limed or fertilized differently during the past 5 to 10 years. Whether or not the explanation for large differences in tests is found, split the field and apply basic treatments of lime and fertilizer according to need.

If there is no consistent pattern of high and low tests, select the median test, which is the test that falls in the middle of a ranking of tests from the area from low to high. If no explanation for large differences in tests is found, consider taking a new set of samples.

Cation-exchange capacity. Chemical elements exist in solution as cations (positively charged ions) or anions (negatively charged ions). In the soil solution, the plant nutrients hydrogen (H), calcium (Ca), magnesium (Mg), potassium (K), ammonium (NH_4), iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) exist as cations. The same is true for nonplant nutrients

Table 11.01. Ratings of Soil Tests

Test	Rating[a]
Water pH	100
Salt pH	30
Buffer pH	30
Exchangeable H	10
Phosphorus	85
Potassium	70
Boron (alfalfa)	60
Boron (corn and soybeans)	10
Iron (pH > 7.5)	30
Iron (pH < 7.5)	10
Organic matter	75
Calcium	40
Magnesium	40
Cation-exchange capacity	60
Sulfur	40
Zinc	45
Manganese (pH > 7.5)	40
Manganese (pH < 7.5)	10
Copper (organic soils)	20
Copper (mineral soils)	5

[a]On a scale of 0 to 100; 100 indicates a very reliable, useful, and cost-effective test, and 0 indicates a test of little value.

such as sodium (Na), barium (Ba), and metals of environmental concern, including mercury (Hg), cadmium (Cd), chromium (Cr), and others. Cation-exchange capacity is a measure of the amount of attraction for the soil with these chemical elements.

In soil, a high cation-exchange capacity is desirable, but not necessary, for high crop yields, as it is not a direct determining factor for yield. Cation-exchange capacity in soil arises from negatively charged electrostatic charges in minerals and organic matter.

Depending on the amount of clay and humus, soil types have a characteristic amount of cation exchange. Sandy soils have up to 4 milliequivalent (meq) per 100 grams of soil; light-colored silt loam soils have 8 to 12 meq; dark-colored silt loam soils have 15 to 22 meq; and clay soils have 18 to 30 meq.

Cation-exchange capacity facilitates retention of positively charged chemical elements from leaching, yet it gives nutrients to a growing plant root by an exchange of hydrogen (H). Farming practices that reduce soil erosion and maintain soil humus favor the maintenance of cation-exchange capacity. The cation-exchange capacity of organic residues is low but increases as the residues convert to humus, which requires from 5 years to centuries.

Plant Analyses

Plant analyses can be useful in diagnosing problems, in identifying hidden hunger, and in determining whether current fertility programs are adequate. For example, they often provide more reliable measures of micronutrient and secondary nutrient problems than do soil tests.

How to sample. When making a plant analysis to diagnose a problem, select paired samples of comparable plant parts representing the abnormal and normal plants. Abnormal plants selected should represent the first stages of a problem.

When using the technique to diagnose hidden hunger in corn, sample several of the leaves opposite and below the ear at early tassel time. For soybeans, sample the most recent fully developed leaves and petioles at early podding. Samples taken later will not indicate the nutritional status of the plant. After collecting the samples, deliver them immediately to the laboratory. They should be air-dried if they cannot be delivered immediately or if they are going to be shipped.

Environmental factors may complicate the interpretation of plant analysis data. The more information provided concerning a particular field, the more reliable the interpretation will be. Suggested critical nutrient levels are provided in Table 11.02. Lower levels may indicate a nutrient deficiency.

Fertilizer Management Related to Tillage Systems

Fertilizer management will be affected by tillage systems because relatively immobile materials such as limestone, phosphorus, and potassium move slowly in most soils unless they are physically mixed by tillage operations. Such "stratification" of nutrients, with higher concentrations developing near the surface, has been well documented in a number of studies but has not been shown to reduce yields of corn or soybeans in Illinois. Limited research indicates that plants develop more roots near the soil surface in conservation-tillage systems, due apparently to both the improved moisture conditions caused by the surface mulch of crop residues and the higher levels of available nutrients. With continued reduced tillage practices, soil fertility levels at deeper depths may be

Table 11.02. Suggested Critical Plant Nutrient Levels for Corn and Soybeans

Crop	Plant part	N	P	K	Ca	Mg	S	Zn	Fe	Mn	Cu	B
		percent						*ppm*				
Corn	Leaf opposite and below the ear at tasseling	2.9	0.25	1.90	0.40	0.15	0.15	15	25	15	5	10
Soybeans	Fully developed leaf and petiole at early podding	...	0.25	2.00	0.40	0.25	0.15	15	30	20	5	25

N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, S = sulfur, Zn = zinc, Fe = iron, Mn = manganese, Cu = copper, B = boron.

depleted such that future soil fertility practices may need adaptation.

Soil tests are important for phosphorus, potassium, and limestone management under any tillage system. Consult the earlier section on "How to sample," and make sure the samples are taken from the full 7-inch depth. If either limestone (which raises pH) or nitrogen fertilizer (which lowers pH) is applied to the surface and not incorporated with tillage, pH tests of the upper 2 inches of soil are needed to aid in the management of some herbicides.

See guidelines for adjusting limestone application rates under different tillage systems. For any system, the rate of application information in the later section on "Phosphorus and Potassium" is valid.

Nitrogen fertilizer management may be affected to a limited extent by changing tillage systems. The information in the section on "Nitrogen" will be valid in all tillage systems, with only the following exceptions:

- Where crop residue is present, a coulter may be needed in front of an applicator knife to properly inject anhydrous ammonia or liquid nitrogen fertilizers.
- In no-till systems, where the surface soil may be firm, special care is needed to make sure that the slit left by an ammonia applicator knife is completely closed to prevent nitrogen loss through the escape of gaseous ammonia.
- Because crop residue in reduced-tillage systems may inhibit urea or urea-containing fertilizers from making direct contact with the soil and thus increase the possibility of nitrogen loss through volatilization, these materials should be mechanically incorporated. Urease inhibitors will aid in preventing this loss.
- The higher moisture conditions under a residue mulch may also cause a higher rate of nitrogen loss through denitrification. Judicious management—including timing of application and the use of nitrification inhibitors—may help avoid significant denitrification losses.
- A risk of occasional anhydrous ammonia damage to corn seed and seedlings exists in fields with any tillage system, especially when the soil is dry, the ammonia is placed shallow, or corn is planted immediately after ammonia application. Corn in no-till fields seems to be particularly vulnerable to such damage in spring preplant ammonia applications whenever the seed is placed directly over the ammonia band. Keeping the anhydrous ammonia and the corn separated in either distance or time will reduce the potential for this problem.

Starter fertilizer. Starter fertilizer is more effective than broadcast applications under cool, moist conditions when phosphorus soil test levels are low, irrespective of tillage system. At high soil test levels, starter fertilizer often results in early growth response on conventional tillage systems but seldom results in increased yield at harvest.

Early season growth of no-till corn is frequently less vigorous than conventional tillage. This slower growth is likely the result of cooler soil temperatures and higher soil moisture conditions associated with the high residue mulch. Both of these conditions tend to slow root growth and thus the ability of the plant to absorb nutrients.

In a 3-year study at four locations, starter fertilizer placed 2 inches below and 2 inches to the side of the seed increased grain yield at 10 of the 11 site years (Table 11.03). Study results revealed several important considerations when deciding whether to use starter fertilizer for no-till corn.

1. Nitrogen provided the majority of the response at Ashton, Pana, and Oblong. The summary table does not show this for Oblong, but the individual-year data show that nitrogen was the most important element in 2 of the 3 years.

Table 11.03. Effect of Starter Fertilizer on Grain Yield of No-Till Corn

Starter fertilizer (lb/A)			Location/previous crop			
N	P_2O_5	K_2O	Ashton/corn	Gridley/soybean	Pana/soybean	Oblong/soybean
			yield (bu/A)			
0	0	0	131	120	128	146
25	0	0	141	123	136	150
25	30	0	147	129	139	155
25	30	20	146	137	133	160

N = nitrogen, P_2O_5 = phosphorus, K_2O = potassium.

2. Addition of phosphorus with the nitrogen increased yield more than enough to pay for the phosphorus. This was true even at Ashton, which had a soil test level in excess of 90 pounds of phosphorus per acre.

3. Including potassium in the starter did not significantly affect yield at either Ashton or Pana. At the other two locations, potassium had a significant impact in 1 of the 3 years of the study. At Gridley, the increase from potassium occurred in a year with a wet spring, which resulted in delayed planting, followed by very dry conditions during early plant growth. Since this was a long-term no-till field, the inherent potassium was primarily in the upper inch of the soil profile, where root activity was limited during the dry period. There was adequate moisture at the 4-inch depth for good root activity and potassium uptake from the fertilizer band. At Oblong, the soil test potassium was low. In the year in which potassium had not been broadcast prior to planting, there was good response to potassium in the starter. However, in the other 2 years, when potassium was broadcast, there was no response to starter potassium.

Attempts to attain the starter response with other application techniques met with mixed success. While placement of up to 10 pounds of nitrogen per acre directly with the seed increased yield, the increase was not as consistent as with 2 x 2 starter. And in a dry spring, placement of as little as 10 pounds of nitrogen per acre significantly reduced stand in some experiments. Placement of a band of nitrogen (25-0-0) or nitrogen plus phosphorus (25-30-0) on the soil surface near the seed row resulted in higher average yields than with no starter, but yield increases were not as high or as consistent as for the banded treatments.

Lime

Soil acidity is one of the most serious limitations to crop production. Acidity is created by a removal of bases by harvested crops, leaching, and an acid residual that is left in the soil from nitrogen fertilizers. During the last several years, limestone use has tended to decrease in Illinois while crop yields and nitrogen fertilizer use have increased (Figure 11.03).

At the present rate of limestone use, no lime is being added to correct the acidity created by the removal of bases or the acidity created in prior years that has not been corrected. A soil test every 4 years is the best way to check on soil acidity levels.

The effect of soil acidity on plant growth. Soil acidity affects plant growth in several ways. Whenever soil pH is low (and acidity is high), several situations may exist:

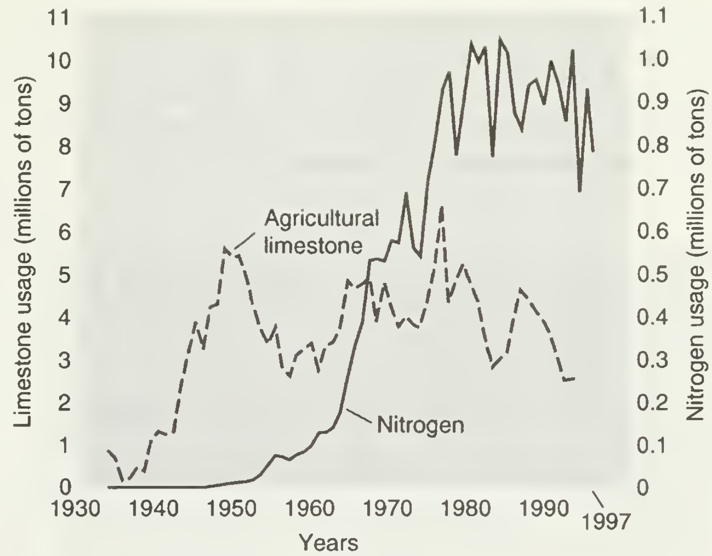


Figure 11.03. Use of agricultural limestone and commercial nitrogen fertilizer, 1930–97.

A. The concentration of soluble metals may be toxic. Damage from excess solubility of aluminum and manganese due to soil acidity has been shown in field research.

B. Populations and the activity of the organisms responsible for transformations involving nitrogen, sulfur, and phosphorus may be altered.

C. Calcium may be deficient. This usually occurs only when the cation-exchange capacity of the soil is extremely low.

D. Symbiotic nitrogen fixation in legume crops is impaired greatly. The symbiotic relationship requires a narrower range of soil reaction than does the growth of plants not relying on nitrogen fixation.

E. Acidic soils are poorly aggregated and have poor tilth. This is particularly true for soils that are low in organic matter.

F. The availability of mineral elements to plants may be affected. Figure 11.04 shows the relationship between soil pH and nutrient availability. The wider the dark bar, the greater the nutrient availability. For example, the availability of phosphorus is greatest in the pH range between 5.5 and 7.5, dropping off below 5.5. Because the availability of molybdenum is increased greatly as soil acidity is decreased, molybdenum deficiencies usually can be corrected by liming.

Suggested pH goals. For cash-grain systems (no alfalfa or clover), maintaining a pH of at least 6.0 is a realistic goal. If the soil test shows that the pH is 6.0 or

less, apply limestone. After the initial investment, it costs little more to maintain a pH at 6.5 than at 6.0. The profit over 10 years will be little affected because the increased yield will approximately offset the cost of the extra limestone plus interest.

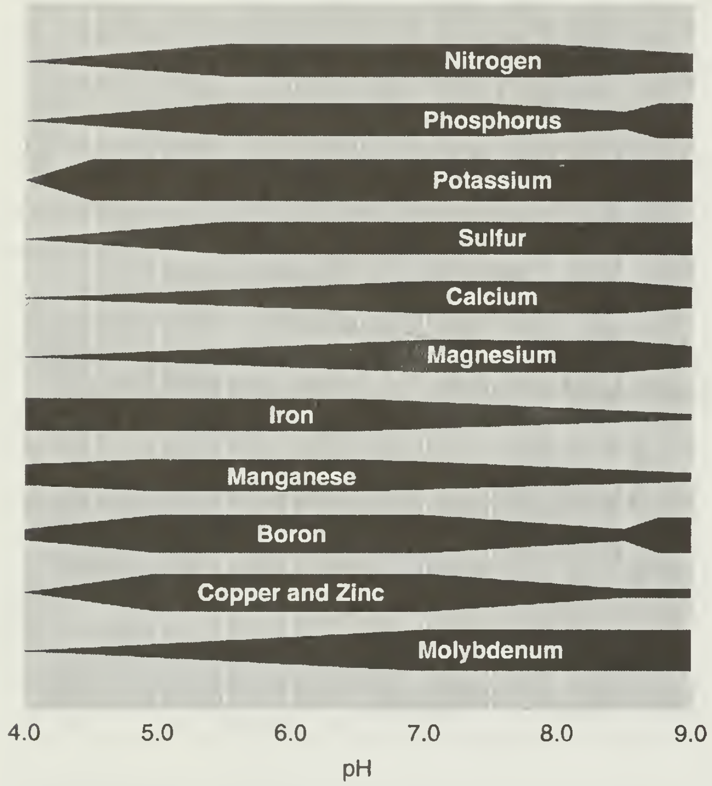


Figure 11.04. Available nutrients in relation to pH.

Research indicates that a profitable yield response from raising the pH above 6.5 in cash-grain systems is unlikely.

For cropping systems with alfalfa and clover, aim for a pH of 6.5 or higher unless the soils have a pH of 6.2 or higher without ever being limed. In those soils, neutral soil is just below plow depth; it will probably not be necessary to apply limestone.

Liming treatments based on soil tests. The limestone requirements in Figure 11.05 assume the following:

A. A 9-inch plowing depth. If plowing is less than 9 inches, reduce the amount of limestone; if more than 9 inches, increase the lime rate proportionately. *In no-till systems, use a 3-inch depth for calculations (one-third the amount suggested for soil moldboard-plowed 9 inches deep).*

B. Typical fineness of limestone. Ten percent of the particles are greater than 8-mesh; 30 percent pass an 8-mesh and are held on 30-mesh; 30 percent pass a 30-mesh and are held on 60-mesh; and 30 percent pass a 60-mesh.

C. A calcium carbonate equivalent (total neutralizing power) of 90 percent. The rate of application may be adjusted according to the deviation from 90.

Instructions for using Figure 11.05 are as follows:

1. Use Chart I for grain systems and Chart II for alfalfa, clover, and lespedeza.

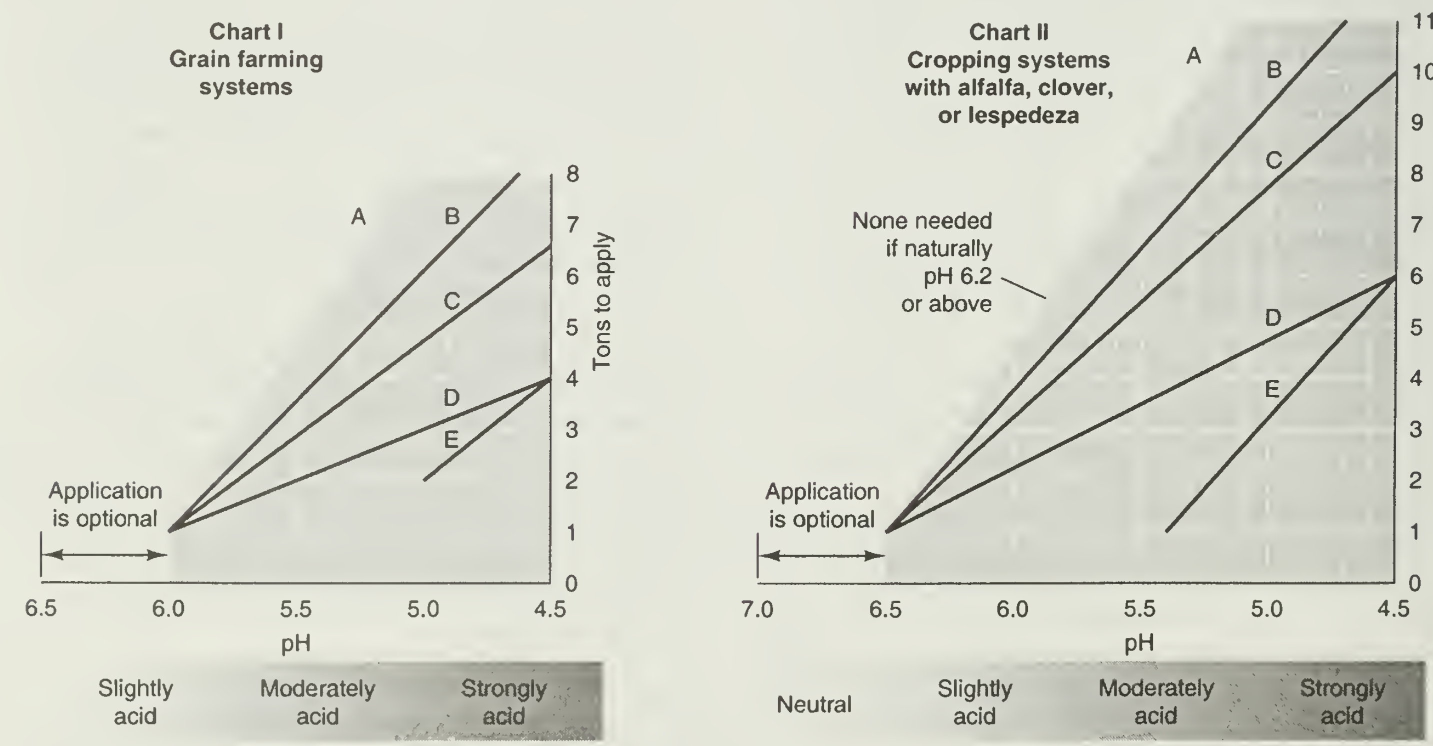


Figure 11.05. Suggested limestone rates based on soil type, pH, cropping systems, and 9-inch depth of tillage.

2. Decide which classification fits the soil:
   a. Dark-colored silty clays and silty clay loams (CEC > 24)
   b. Light- and medium-colored silty clays and silty clay loams; dark-colored silt and clay loams (CEC 15–24)
   c. Light- and medium-colored silt and clay loams; dark- and medium-colored loams; dark-colored sandy loams (CEC 8–15)
   d. Light-colored loams; light- and medium-colored sandy loams; sands (CEC < 8)
   e. Muck and peat

Soil color is related to organic matter. Light-colored soils usually have less than 2.5 percent organic matter; medium-colored soils have 2.5 to 4.5 percent organic matter; dark-colored soils have more than 4.5 percent organic matter; sands are excluded.

Limestone quality. Limestone quality is measured by the neutralizing value and the fineness of grind. The neutralizing value of limestone is measured by its calcium carbonate equivalent: the higher this value, the greater the limestone's ability to neutralize soil acidity. Rate of reaction is affected by particle size; the finer that limestone is ground, the faster it will neutralize soil acidity. Relative efficiency factors have been determined for various particle sizes (Table 11.04).

If you are liming an acid soil just before seeding alfalfa, it is important to have highly reactive particles; the figures for 1 year are the best guide. If you apply lime before corn, the 4-year values are adequate.

The quality of limestone is defined as its effective neutralizing value (ENV). This value can be calculated for any liming material by using the efficiency factors in Table 11.04 and the calcium carbonate equivalent for the limestone in question. The "typical" limestone on which Figure 11.05 is based has an ENV of 46.35 for 1 year and 67.5 for 4 years.

The Illinois Department of Agriculture, in cooperation with the Illinois Department of Transportation, collects and analyzes limestone samples from quarries that wish to participate in the Illinois Voluntary

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WORKSHEET

Evaluation for 1 year after application of lime

			Efficiency factor	
% of particles greater than 8-mesh	=	$\frac{\_\_\_}{100}$	x 5	=
% of particles that pass 8-mesh and are held on 30-mesh	=	$\frac{\_\_\_}{100}$	x 20	=
% of particles that pass 30-mesh and are held on 60-mesh	=	$\frac{\_\_\_}{100}$	x 50	=
% of particles that pass 60-mesh	=	$\frac{\_\_\_}{100}$	x 100	=

Total fineness efficiency _______

$$\text{ENV} = \text{total fineness efficiency} \times \frac{\%\ \text{calcium carbonate equivalent}}{100}$$

$$\text{Correction factor} = \frac{\text{ENV of typical limestone (46.35)}}{\text{ENV of sampled limestone (\_\_\_)}}$$

Correction factor x limestone requirement (from Figure 11.05) = _____tons of sampled limestone needed per acre

Evaluation for 4 years after application of lime

			Efficiency factor	
% of particles greater than 8-mesh	=	$\frac{\_\_\_}{100}$	x 15	=
% of particles that pass 8-mesh and are held on 30-mesh	=	$\frac{\_\_\_}{100}$	x 45	=
% of particles that pass 30-mesh and are held on 60-mesh	=	$\frac{\_\_\_}{100}$	x 100	=
% of particles that pass 60-mesh	=	$\frac{\_\_\_}{100}$	x 100	=

Total fineness efficiency _______

$$\text{ENV} = \text{total fineness efficiency} \times \frac{\%\ \text{calcium carbonate equivalent}}{100}$$

$$\text{Correction factor} = \frac{\text{ENV of typical limestone (67.5)}}{\text{ENV of sampled limestone (\_\_\_)}}$$

Correction factor x limestone requirement (from Figure 11.05) = _____tons of sampled limestone needed per acre

Example from the worksheet

1 year

$$\frac{13.1\%}{100} \times 5 = 0.65$$

$$\frac{40.4\%}{100} \times 20 = 8.08$$

$$\frac{14.9\%}{100} \times 50 = 7.45$$

$$\frac{31.6\%}{100} \times 100 = \underline{\underline{31.60}}$$

Total fineness efficiency: 47.78

$$\text{ENV} = 47.78 \times \frac{86.88}{100} = 41.51$$

$$\frac{46.35}{41.51} \times 3 = 3.35 \text{ tons per acre}$$

4 years

$$\frac{13.1\%}{100} \times 15 = 1.96$$

$$\frac{40.4\%}{100} \times 45 = 18.18$$

$$\frac{14.9\%}{100} \times 100 = 14.90$$

$$\frac{31.6\%}{100} \times 100 = \underline{\underline{31.60}}$$

Total fineness efficiency: 66.64

$$\text{ENV} = 66.64 \times \frac{86.88}{100} = 57.9$$

$$\frac{67.5}{57.9} \times 3 = 3.5 \text{ tons per acre}$$

Table 11.04. Efficiency Factors for Various Limestone Particle Sizes

	Efficiency factor	
Particle sizes	1 year after application	4 years after application
Greater than 8-mesh	5	15
8- to 30-mesh	20	45
30- to 60-mesh	50	100
Passing 60-mesh	100	100

Limestone Program. These analyses, along with the calculated correction factors, are available from the Illinois Department of Agriculture, Division of Plant Industries and Consumer Services, P.O. Box 19281, Springfield, IL 62794-9281, in the annual publication Illinois Voluntary Limestone Program Producer Information. To calculate the ENV for materials not reported in that publication, obtain the analysis of the material in question from the supplier and use the worksheet provided here for making calculations.

As an example, consider a limestone that has a calcium carbonate equivalent of 86.88 percent and a sample that has 13.1 percent of the particles greater than 8-mesh, 40.4 percent that pass 8-mesh and are held on 30-mesh, 14.9 percent that pass 30-mesh and are held on 60-mesh, and 31.6 percent that pass 60-mesh. Assume that 3 tons of typical limestone are needed per acre (according to Figure 11.05). The amounts of limestone with these characteristics that would be needed to meet the 3-ton recommendation would be 3.35 tons and 3.5 tons on a 1- and 4-year basis, respectively. (See the calculations to the left.)

At rates up to 6 tons per acre, if high initial cost is not a deterrent, the entire amount may be applied at one time. If cost is a factor and the amount of limestone needed is 6 tons or more per acre, apply it in split applications of about two-thirds the first time and the remainder 3 or 4 years later.

Fluid lime suspensions (liquid lime). These products are obtained by suspending very finely ground limestone in water. Several industrial by-products with liming properties also are being land-applied as suspensions, either because they are too fine to be spread dry or they are already in suspension. These by-products include residue from water treatment plants, cement plant stack dusts, paper mill sludge, and other waste products. These materials may contain as much as 50 percent water.

The chemistry of liquid liming materials is the same as that of dry materials. Research results have confirmed that the rate of reaction and the neutralizing power for liquid lime are the same as for dry materials when particle sizes are the same.

Results from one study indicate that application of liquid lime at the rate of material calculated by the following equation is adequate to maintain soil

pH for at least 4 years at the same level as typical lime.

$$\frac{\text{ENV of typical limestone [use 46.35]}}{100\ (\text{fineness efficiency factor}) \times \frac{\%\ \text{calcium carbonate, equivalent, dry matter basis}}{100} \times \frac{\%\ \text{dry matter}}{100}}$$

x tons of limestone needed per acre = tons of liquid lime needed per acre

During the first few months after application, the liquid material will provide a more rapid increase in pH than will typical lime, but after that the two materials will provide equivalent pH levels in the soil.

As an example, assume a lime need of 3 tons per acre (based on Figure 11.05) and liquid lime that is 50 percent dry matter and has a calcium carbonate equivalent of 97 percent on a dry-matter basis. The rate of liquid lime needed would be calculated as follows:

$$\frac{46.35}{100 \times \frac{97}{100} \times \frac{50}{100}} \times 3 = 2.87 \text{ tons of liquid lime per acre}$$

Lime incorporation. Lime does not react with acidic soil very far from the particle, but special tillage operations to mix lime with soil usually are not necessary in systems that use a moldboard plow. Systems of tillage that use a chisel plow, disk, or field cultivator rather than a moldboard plow, however, may not mix limestone deeper than 4 to 5 inches.

Calcium-Magnesium Balance in Illinois Soils

Soils in northern Illinois usually contain more magnesium than those in central and southern Illinois because of the high magnesium content in the rock from which the soils developed and because northern soils are geologically younger. This relatively high level of magnesium has caused speculation as to whether the level is too high. Although there have been reported suggestions that either gypsum or low-magnesium limestone should be applied, no research data have been put forth to justify concern over a too-narrow ratio of calcium to magnesium.

On the other hand, concern is justified over a soil magnesium level that is low—because of its relationship with hypomagnesaemia, a prime factor in grass tetany or milk fever in cattle. This concern is more relevant to forage production than to grain production. Very high potassium levels (more than 500 pounds per acre) combined with low soil magnesium levels contribute to low-magnesium grass forages. Research data to establish critical magnesium levels are very limited. However, levels of soil magnesium less than 60 pounds per acre on sands and 150 pounds per acre on silt loams are regarded as low.

Calcium and magnesium levels of agricultural limestone vary among quarries in the state. Dolomitic limestone (material with an appreciable magnesium content, as high as 21.7 percent MgO or 46.5 percent $MgCO_3$) occurs predominantly in the northern three tiers of Illinois counties, in Kankakee County, and in Calhoun County. Limestone occurring in the remainder of the state is predominantly calcitic (high calcium), although it is not uncommon for it to contain 1 to 3 percent $MgCO_3$.

There are no agronomic reasons to recommend either that grain farmers in northern Illinois bypass local limestone sources, which are medium to high in magnesium, and pay a premium for low-magnesium limestone from southern Illinois or that grain farmers in southern Illinois order limestone from northern Illinois quarries because of magnesium content.

For farmers with a livestock program or who produce forages in the claypan and fragipan regions of the south, where soil magnesium levels may be marginal, it is appropriate to use a soil test to verify conditions and to use dolomitic limestone or magnesium fertilization or to add magnesium to the feed.

Nitrogen

About 40 percent of the original nitrogen and organic-matter content has been lost from typical Illinois soils since farming began, the result of erosion and increased oxidation of organic matter. Erosion reduces the nitrogen content of soils because the surface soil is richest in nitrogen and this erodes first. Farming practices that improve aeration of the soil, including improved drainage and tillage, have increased the rate of organic matter degradation. Further nitrogen losses result from denitrification and leaching.

Because harvested crops remove more nitrogen than any other nutrient from Illinois soils, the use of nitrogen fertilizer is necessary if Illinois agriculture is to be competitive in the world market. Economics, along with concern for the environment, make it imperative that all nitrogen fertilizers be used as efficiently as possible. Factors that influence efficiency are discussed in the following sections.

Nitrogen Recommendation Systems

Nitrogen recommendations in the humid regions of the Corn Belt have been based primarily on expected yield, with an adjustment for previous crop and management programs. Although this system has worked well, there are documented reports of near-optimal corn yields with little or no supplemental nitrogen. Such results have encouraged researchers to develop a reliable and practical soil nitrogen test that would let farmers and advisers identify conditions where the nitrogen application rate could be modified to enhance crop profits without harming the environment.

Total soil nitrogen. Because 5 percent of soil organic matter is nitrogen, some have theorized that organic-matter content of a soil could be used as an estimate of the amount of supplemental nitrogen that would be needed for a crop. As a rough guideline, many assume that 2 percent of the organic nitrogen will be released each year. This would amount to a release of 100 pounds of nitrogen per acre on fields with 5 percent organic matter. Attempts to use this procedure have been unsuccessful because mineralization of organic matter varies significantly over time due to variation in available soil moisture. Additionally, soils high in organic matter usually have a higher yield potential due to their ability to provide a better environment for crop growth.

Early-spring nitrate nitrogen. This procedure has been used for several years in the more arid parts of the Corn Belt (west of the Missouri River) with reasonable success. It involves collecting soil samples in 1-foot increments to a 2- to 3-foot depth in early spring for analysis of nitrate nitrogen. Although the use of the information varies somewhat from state to state, the consensus is to reduce the normal nitrogen recommendation by the amount found in the soil profile sampled. Results obtained by scientists in both Wisconsin and Michigan have found this procedure to work well, but research in Iowa indicated that the procedure did not accurately predict nitrogen needs.

Since samples are collected in early spring, this procedure measures potential for nitrogen carryover from the previous crop. It thus will have the greatest potential for success on continuous corn, especially in fields where adverse growing conditions have limited yields the previous year. Additional work is needed to ascertain the sampling procedure that will best characterize the field conditions, especially when nitrogen has been injected in prior years. When excessive precipitation is received in late spring or early summer, this procedure will not likely be successful because most of the nitrogen that is detected early may be leached or denitrified before the plant has an opportunity to absorb it from the soil.

Late-spring nitrate nitrogen. Success with this procedure was first observed with work in Vermont. Follow-up work in some of the Corn Belt states also indicates that the procedure accurately characterizes nitrogen needs. Soil samples are collected to a 1-foot depth when corn plants are 6 to 12 inches tall and analyzed for nitrate nitrogen. University agronomists suggest that no additional nitrogen be applied when soil test levels exceed 22 to 25 parts per million and that full rate be applied if nitrate nitrogen levels are less than 10 parts per million. They suggest proportional adjustments in nitrogen rates when test levels are between 10 and 26 parts per million. To minimize the potential for decreased yield that might be caused by delayed nitrogen application, agronomists at Iowa State University suggest that 50 to 70 percent of the normal nitrogen application be applied preplant. If the fertilizer was broadcast, they suggest collecting 16 to 24 core samples within an area not exceeding 10 acres. If the fields have been fertilized with anhydrous ammonia, they suggest a modified soil test. The modified test can be used under the following conditions: (a) the rate of ammonia application did not exceed 125 pounds of nitrogen per acre; (b) the soil sample is derived from at least 24 cores collected without regard to location of ammonia injection bands; and (c) fertilizer nitrogen recommendations are adjusted to reflect that one-third of the nitrogen applied was not revealed by the soil test.

By sampling later in the season, this test provides a measure of the mineralization of organic nitrogen that has occurred and the amount of residual carryover that is still present in the soil. Obvious limitations of this procedure include these: (a) its use only on fields that receive sidedress application of nitrogen; (b) the short time available between sampling and the need to apply fertilizer, which could be especially critical in wet years and could result in corn plants becoming too large to use conventional application equipment; and (c) no existing correlation for use of the procedure on fields that have received a banded nitrogen application.

Because none of the nitrogen soil test procedures have given adequate crop nitrogen requirement predictions, their use is not encouraged under Illinois conditions. It is suggested that nitrogen rates be determined using the following materials as a guide.

Yield potential. Research trials conducted by the University of Illinois Crop Sciences Department have demonstrated that use of the following system for determining nitrogen rate will optimize yield. There are years when this system will recommend more nitrogen than needed, but very few years in which the recommendation will be so low as to markedly re-

duce yield. It appears that use of this system will help reduce the amount of nitrogen being lost to the environment.

The worksheet on page 90 is designed to help you determine your fertilizer nitrogen need. You can also use this equation to calculate nitrogen need for corn:

Fertilizer nitrogen needed = (Target yield in bushels x 1.2 lb N/bushel) – legume N – manure N – incidental N

Target yield is one of the major considerations in determining the optimum rate of nitrogen application for corn. The target yield should be established for each field, taking into account the soil type and management level under which the crop will be grown. If yield records are available, use the 5-year average yield as the basis. When figuring the average, eliminate years of abnormally low yields that resulted from drought or other weather-related conditions. Increase the average yield by 5 percent because of improved varieties and cultural practices.

If yield records are not available for a particular field, suggested productivity-index values are given in Illinois Agricultural Experiment Station Bulletin 778, *Soils of Illinois*. Yield goals are presented for both basic and high levels of management. Annual variations in yield of 20 percent above or below the productivity-index values are common because of variations in weather conditions. However, applying nitrogen fertilizer for yields possible in the most favorable year will not result in maximum net return when averaged over all years.

The 1.2 lb N/bushel coefficient was derived assuming a corn-to-nitrogen price ratio (price of corn per bushel divided by the price of N per pound) between 10:1 and 20:1. If the price ratio goes above 20:1, then the optimum rate would increase to 1.3 lb N/bushel.

Take credit for "home-grown" nitrogen, including corn following a legume crop such as soybean, alfalfa, or clover and for manure applied to the field. (See the subsection about rate adjustments on page 93.) Incidental nitrogen is that nitrogen applied with phosphates, applied as a part of the starter fertilizer, and/or applied as a carrier for herbicides.

Evaluation of nitrogen recommendation systems for corn. Experiments were conducted at 77 locations around Illinois to evaluate the potential for using the nitrate nitrogen soil test systems to improve nitrogen recommendations. Use of the systems was compared to use of yield potential, multiplied by a factor, minus adjustments for previous crops and legumes. Considering only those locations exhibiting a significant response to applied fertilizer nitrogen, all three systems —those based on yield potential with adjustments for home-grown and incidental nitrogen, and those based on yield potential with an adjustment for the amount of nitrate nitrogen observed in the soil at early spring or at pre-sidedress time—gave recommendations within 8 pounds of the amount needed for the fields on the average (Table 11.05). Adjustments based on the early spring nitrate nitrogen test resulted in recommendations about 25 pounds less than needed to obtain the most return per acre.

None of the three systems provided accurate recommendations for fields where adverse weather conditions limited yield potential far below expectation and limited yield response to applied nitrogen (Table 11.06). At locations where manure had been applied prior to planting, all three recommendation systems predicted a need for little supplemental fertilization.

Based on results so far, none of the nitrogen soil test procedures now available offers enough improved accuracy or reliability over the yield potential system described earlier to justify its use on Illinois fields. An exception appears to be on fields that have received a

Table 11.05. Relationship Between Experimentally Derived, Economically Optimum Nitrogen Rates and Nitrogen Recommendations from Three Recommendation Systems

				Recommendation system		
Locations	Yield goal (bu/A)	Optimum yield (bu/A)	Optimum N rate (bu/A)	PY[a] (lb N/acre)	PPNT[b] (lb N/acre)	PSNT[c] (lb N/acre)
Responding sites: 44	139	161	138	137	107	130
Nonresponding sites: 33	143	145	0	111	76	113

[a] Proven yield. University of Illinois Department of Crop Sciences recommendations using proven yield.
[b] Preplant nitrogen test. U of I Department of Crop Sciences recommendations, minus nitrate content in top 2 feet of surface soil in early spring.
[c] Pre-sidedress nitrogen test. Iowa State University Department of Agronomy nitrogen recommendations.

Nitrogen Rate Worksheet for Corn

1. Determine your average yield for the last 5-year period:

Yield last 5 years (bu/acre)					Sum across years	Divided by number of years	Average
Year 1	Year 2	Year 3	Year 4	Year 5			

2. Multiply average yield by 1.05 to obtain target yield; the increase of 0.05 accounts for increased yield potential due to improved variety and cultural practices.

	x 1.05	Bu/acre
Average yield		Target yield

3. Multiply target yield by 1.20 lb N/bu to obtain N needed per acre:

	x 1.20	Lb N/acre
Target yield		N needed

4. Reduce N needed by subtracting all N credits (adjust for all of the following that apply):
   a) Previous crop of soybeans (40 lb N/acre). ______
   b) Previous crop of alfalfa/clover (> 5 plants/ft = 100 lb N; 2–4 plants/ft = 50 lb N). ______
   c) Application of ammoniated phosphate (multiply lb material by percent N). Ex.: 200 lb 18-46-0 = 200 x 0.18 = 36 lb N/acre. ______
   d) Manure application (total lb N in manure divided by 2). ______
   e) Weed and feed N (multiply gallon per acre times 3 for 28% N or times 3.5 for 32% N solutions). ______
   f) Starter (multiply rate by percent N). ______
   g) N in irrigation water (inches irrigation water x ppm $NO_3 - N \times 0.23$). ______

   Total N credits (a + b + c + d + e + f + g) ______

5. Amount N to apply: (N needed) – (N credit)

Table 11.06. Relationship Between Experimentally Derived, Economically Optimum Nitrogen Rates and Nitrogen Recommendations from Three Recommendation Systems as Influenced by Manure Application, Environmental Factors, and Previous Crop

Locations	Yield goal (bu/A)	Optimum yield (bu/A)	Optimum N rate (bu/A)	Recommendation system PY[a] (lb N/acre)	PPNT[b] (lb N/acre)	PSNT[c] (lb N/acre)
Manured sites: 9	144	185	0	24	10	36
Drought-affected sites: 8	153	99	0	163	118	128
Forage legume sites: 4	148	164	0	102	74	85

[a]Proven yield. University of Illinois Department of Crop Sciences recommendations using proven yield.
[b]Preplant nitrogen test. U of I Department of Crop Sciences recommendations, minus nitrate content in top 2 feet of surface soil in early spring.
[c]Pre-sidedress nitrogen test. Iowa State University Department of Agronomy nitrogen recommendations.

broadcast application of manure or other materials containing organic nitrogen. In those cases, if the nitrate nitrogen test exceeds 25 parts per million at the time the corn is 6 to 12 inches tall, there is no need for additional nitrogen fertilizer.

Soybeans. Based on average Illinois corn and soybean yields from 1995 and 1996 and average nitrogen content of the grain for these two crops, the total nitrogen removed per acre by soybeans (151 pounds) was greater than that removed by corn (91 pounds). Research results from the University of Illinois, however, indicate that when properly nodulated soybeans were grown at the proper soil pH, the symbiotic fixation was equivalent to 63 percent of the nitrogen removed in harvested grain. Thus, the net nitrogen removal by soybeans (56 pounds) was less than that of corn (91 pounds).

This net removal of nitrogen by soybeans in 1995–96 was equivalent to 29 percent of the amount of fertilizer nitrogen used in Illinois. On the other hand, symbiotic fixation of nitrogen by soybeans in Illinois (465,169 tons of nitrogen) was equivalent to 50 percent of the fertilizer nitrogen used in Illinois.

Even though there is a rather large net nitrogen removal from soil by soybeans (56 pounds of nitrogen per acre), research at the University of Illinois has generally indicated no soybean yield increase caused by either residual nitrogen in the soil or nitrogen fertilizer applied for the soybean crop.

1. *Residual from nitrogen applied to corn* (Table 11.07). Soybean yields at four locations were not increased by residual nitrogen in the soil, even when nitrogen rates as high as 320 pounds per acre had been applied to corn the previous year.
2. *Nitrogen on continuous soybeans* (Table 11.08). After 18 years of continuous soybeans at Hartsburg, yields were unaffected by applications of nitrogen fertilizer.
3. *High rates of added nitrogen* (Table 11.09). Moderate rates of nitrogen were applied to soybeans in the first year of a study at Urbana. Rates were increased in the second year so that the higher rates would furnish more than the total nitrogen needs of soybeans. Yields were not affected by nitrogen in the first year, but with 400 pounds per acre of nitrogen, a tendency toward a yield increase occurred

Table 11.07. Soybean Yields at Four Locations as Affected by Nitrogen Applied to Corn the Preceding Year (4-Year Average)

N applied to corn (lb/A)	Soybean yield (bu/A) Aledo	Dixon	Elwood	Kewanee	Average
0	48	40	37	40	41
80	49	40	36	38	41
160	48	39	36	40	41
240	48	42	36	40	41
320	48	42	36	37	41

Table 11.08. Yields of Continuous Soybeans with Rates of Added Nitrogen at Hartsburg

Nitrogen (lb/A)	Soybean yield (bu/A) 1968–71	1954–71
0	43	37
40	42	36
120	43	37

Table 11.09. Soybean Yields at Urbana as Affected by High Rates of Nitrogen

Nitrogen (lb/A)			Soybean yield (bu/A)		
1st year	2nd year	3rd year	1st year	2nd year	3rd year
0	0	0	54	53	40
40	200	200	54	57	41
80	400	400	56	57	45
120	800	800	53	55	42
160	1,600	1,600	55	34	36

in the second and third years. However, the yield increase would not pay for the added nitrogen at current prices.

Kansas researchers have reported soybean yield increases associated with the application of up to 40 pounds nitrogen per acre at the R4 stage of growth. Generally, these responses have occurred on irrigated, high-yielding (check yields of 58 bushel per acre) fields. In 1995 yield increases ranging from 9 to 12 bushels per acre were observed at 3 of 4 locations. The control yield at the nonresponding location was 43 bushel per acre.

Wheat, oats, and barley. The rate of nitrogen to apply on wheat, oats, and barley depends on soil type, crop and variety to be grown, and future cropping intentions (Table 11.10). Light-colored soils (low in organic matter) require the highest rate of nitrogen application because they have a low capacity to supply nitrogen. Deep, dark-colored soils require lower rates of nitrogen application for maximum yields. Estimates of organic-matter content for soils of Illinois may be obtained from Agronomy Fact Sheet SP-36, *Average Organic Matter Content in Illinois Soil Types*, or by using University of Illinois publication AG-1941, *Color Chart for Estimating Organic Matter in Mineral Soils.*

Nearly all modern varieties of wheat have been selected for improved standability, so concern about nitrogen-induced lodging has decreased considerably. Varieties of oats, though substantially improved with regard to standability, will still lodge occasionally; nitrogen should be used carefully. Barley varieties, especially spring barley, are prone to lodging, so rates of nitrogen application shown in Table 11.10 should not be exceeded.

Some wheat and oats in Illinois serve as companion crops for legume or legume-grass seedings. On those fields, it is best to apply nitrogen fertilizer at well below the optimum rate because unusually heavy vegetative growth of wheat or oats competes unfavorably with the young forage seedlings (Table 11.10). Seeding rates for small grains should also be somewhat lower if used as companion seedings.

The introduction of nitrification inhibitors and improved application equipment now provide two options for applying nitrogen to wheat. Research has shown that when the entire amount of nitrogen needed is applied in the fall with a nitrification inhibitor, the resulting yield is equivalent to that obtained when a small portion of the total need was fall-applied and the remainder was applied in early spring. Producers who are frequently delayed in applying nitrogen in the spring because of muddy fields may wish to consider fall application with a nitrification inhibitor. For fields that are not usually wet in the spring, either system of application will provide equivalent yields.

Table 11.10. Recommended Nitrogen Application Rates for Wheat, Oats, and Barley

Soil situation	Organic matter	Fields with alfalfa or clover seeding		Fields with no alfalfa or clover seeding	
		Wheat	Oats and barley	Wheat	Oats and barley
		nitrogen (lb/A)			
Low in capacity to supply nitrogen: inherently low in organic matter (forested soils)	< 2%	70–90	60–80	90–110	70–90
Medium in capacity to supply nitrogen: moderately dark-colored soils	2–3%	50–70	40–60	70–90	50–70
High in capacity to supply nitrogen: deep, dark-colored soils	> 3%	30–50	20–40	50–70	30–50

Table 11.11. Nitrogen Fertilization of Hay and Pasture Grasses

Species	Early spring	After first harvest	After second harvest	Early September
	Time of application			
	----------- *nitrogen (lb/A)* -----------			
Kentucky bluegrass	60–80			(see text)
Orchardgrass	75–125	75–125		
Smooth bromegrass	75–125	75–125		50[a]
Reed canary grass	75–125	75–125		50[a]
Tall fescue for winter use		100–125	100–125	50[a]

[a]Optional if extra fall growth is needed.

Table 11.12. Adjustments in Nitrogen Recommendations

Crop to be grown	After soybeans	1st year after alfalfa or clover: Plants/sq ft 5	2–4	<2	2nd year after alfalfa or clover: Plants/sq ft 5	<5	Manure
	Factors resulting in reduced nitrogen requirement						
	-------- *nitrogen reduction (lb/A)* --------						
Corn	40	100	50	0	30	0	5[a]
Wheat	10	30	10	0	0	0	5[a]

[a]Nitrogen contribution in pounds per ton of manure. See Table 11.13 for adjustments for liquid manure.

The amount of nitrogen needed for good fall growth is not large because the total uptake in roots and tops before cold weather is not likely to exceed 30 to 40 pounds per acre.

Hay and pasture grasses. The species grown, period of use, and yield goal determine optimum nitrogen fertilization (Table 11.11). The lower rate of application is recommended on fields where inadequate stands or moisture limits production.

Kentucky bluegrass is shallow-rooted and susceptible to drought. Consequently, the most efficient use of nitrogen by bluegrass is from an early spring application, with September application a second choice. September fertilization stimulates both fall and early spring growth.

Orchardgrass, smooth bromegrass, tall fescue, and reed canarygrass are more drought-tolerant than bluegrass and can use higher rates of nitrogen more effectively. Because more uniform pasture production is obtained by splitting high rates of nitrogen, two or more applications are suggested.

If extra spring growth can be utilized, make the first nitrogen application in March in southern Illinois, early April in central Illinois, and mid-April in northern Illinois. If spring growth is adequate without extra nitrogen, the first application may be delayed until after the first harvest or grazing cycle to distribute production more uniformly throughout the summer. Total production likely will be less, however, if nitrogen is applied after first harvest rather than in early spring. Usually the second application of nitrogen is made after the first harvest or first grazing cycle; to stimulate fall growth, however, this application may be deferred until August or early September.

Legume-grass mixtures should not receive nitrogen if legumes make up at least 30 percent of the mixture. Because the main objective is to maintain the legume, the emphasis should be on applying phosphorus and potassium rather than nitrogen.

After the legume has declined to less than 30 percent of the mixture, the objective of fertilizing is to increase the yield of grass. The suggested rate of nitrogen is about 50 pounds per acre when legumes make up 20 to 30 percent of the mixture.

Rate Adjustments

In addition to determining nitrogen rates, producers should consider other agronomic factors that influence available nitrogen. These factors include past cropping history and the use of manure (Table 11.12), as well as the date of planting.

Previous crop. Corn following another crop consistently yields better than continuous corn. This is especially true for corn following a legume such as soybeans or alfalfa (Figure 11.06). This is due in part to residual nitrogen from the legumes as the differences in yield between rotations become smaller with increasing nitrogen rates. When no nitrogen was applied, the data indicate that soybeans and alfalfa contributed the equivalent of 65 and 108 pounds of nitrogen per acre, respectively. At the optimum production level, soybeans contributed the equivalent of about 40 pounds of nitrogen per acre. The contribution of legumes, either soybeans or alfalfa, to wheat will be less than the contribution to corn because the oxidation of the organic nitrogen from these legumes will not be as rapid in early spring, when nitrogen needs of small grain are greatest, as it

Table 11.13. Average Composition of Manure

	Nutrients (lb/ton)		
Manure type	Nitrogen (N)	Phosphorus (P_2O_5)	Potassium (K_2O)
Dairy cattle	11	5	11
Beef cattle	14	9	11
Hogs	10	7	8
Chicken	20	16	8
Dairy cattle (liquid)	5(26)[a]	2(11)	4(23)
Beef cattle (liquid)	4(21)	1(7)	3(18)
Hogs (liquid)	10(56)	5(30)	4(22)
Chicken (liquid)	13(74)	12(68)	5(27)

[a]Parenthetical numbers are pounds of nutrients per 1,000 gallons.

is in the summer, when nitrogen needs of corn are greatest.

Corn following oats had a higher yield than continuous corn (Figure 11.06). Although oats are not a legume, a part of this yield differential may be because nitrogen was released from the soil after the oat crop had completed its nitrogen uptake, and thus it was carried over to the next year's corn crop.

Idled acres. Depending on the crop grown, the nitrogen credit from idled acres may be positive or negative. Plowing under a good stand of a legume that had good growth will result in a contribution of 60 to 80 pounds of nitrogen per acre. If either stand or growth of the legume was poor or if corn was no-tilled into a good legume stand that had good growth,

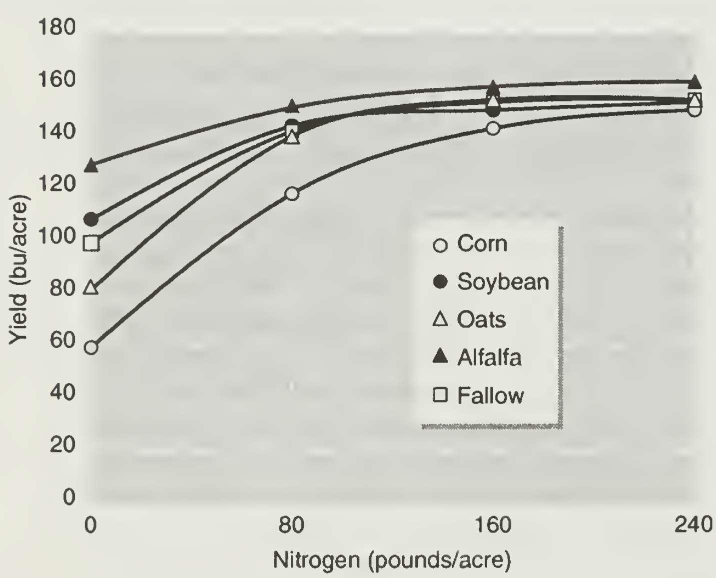

Figure 11.06. Effect of crop rotation and applied nitrogen on corn yield, DeKalb.

the legume nitrogen contribution could be reduced to 40 to 60 pounds per acre. Because most of the net nitrogen gained from first-year legumes is in the herbage, fall grazing reduces the nitrogen contribution to 30 to 50 pounds per acre.

Manure. Nutrient content of manure varies with source and method of handling (Table 11.13). The availability of the total nitrogen content also varies by method of application. When manure is incorporated during or immediately after application, about 50 percent of the total nitrogen in dry manure and 50 to 60 percent of the total nitrogen in liquid manure will be available for the crop that is grown during the year following manure application.

Time of planting. Research at the Northern Illinois Research Center for several years showed that as planting was delayed, less nitrogen fertilizer was required for most profitable yield. Based upon that research, Illinois agronomists suggest that for each week of delay in planting after the optimum date for the area, the nitrogen rate can be reduced 20 pounds per acre down to 80 to 90 pounds per acre as the minimum for very late planting in a corn–soybean cropping system. Suggested reference dates are April 10 to 15 in southern Illinois, April 20 to May 1 in central Illinois, and May 1 to 10 in northern Illinois. This adjustment is of course possible only if the nitrogen is sidedressed.

Because of the importance of planting date, farmers are encouraged not to delay planting just to apply nitrogen fertilizer: plant, then sidedress.

Reactions in the Soil

Efficient use of nitrogen fertilizer requires understanding how nitrogen behaves in the soil. Key points to consider are the change from ammonium (NH_4^+) to nitrate (NO_3^-) and the movements and transformations of nitrate.

A high percentage of the nitrogen applied in Illinois is in the ammonium form or converts to ammonium (anhydrous ammonia and urea, for example) soon after application. Ammonium nitrogen is held by the soil clay and organic matter and cannot move very far until it nitrifies (changes from ammonium to nitrate). In the nitrate form, nitrogen can be lost by either denitrification or leaching (Figure 11.07).

Denitrification. Denitrification is believed to be the main process by which nitrate and nitrite nitrogen are lost, except on sandy soils, where leaching is the major pathway. Denitrification involves only nitrogen that is in the form of either nitrate (NO_3^-) or nitrite (NO_2^-).

The amount of denitrification depends mainly on (a) how long the surface soil is saturated; (b) the tem-

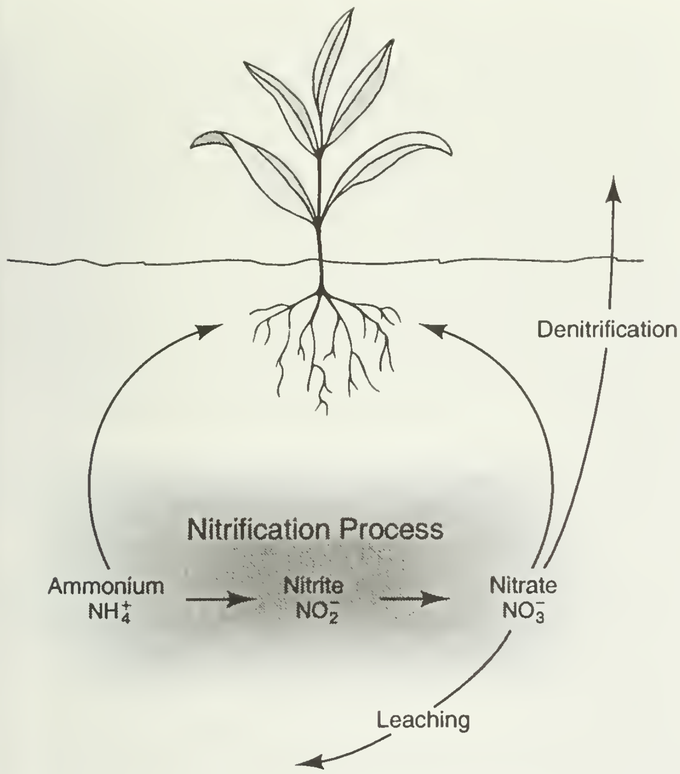

Figure 11.07. Nitrogen reactions in the soil.

perature of the soil and water; (c) the pH of the soil; and (d) the amount of energy material available to denitrifying organisms.

When water stands on the soil or when the surface is completely saturated in late fall or early spring, nitrogen loss is likely to be small because much nitrogen is still in the ammonium rather than nitrate form and because the soil is cool, and denitrifying organisms are not very active.

Many fields in east-central Illinois, and to a lesser extent in other areas, have low spots where surface water collects at some time during the spring or early summer. The flat claypan soils also are likely to be saturated, though not flooded, during that time. Sidedressing would avoid the risk of spring loss on these soils but would not affect midseason loss. Unfortunately, these are the soils on which sidedressing is difficult in wet years.

New scientific procedures now make it possible to directly measure denitrification losses. Results collected over the past few years indicate that when soils were saturated for 3 days or longer, 5 percent of the nitrogen present in the nitrate form was lost per day of saturation.

Leaching. In silt loams and clay loams, 1 inch of rainfall moves down about 5 to 6 inches, though some of the water moves in large pores farther through the profile and carries nitrates with it.

In sandy soils, each inch of rainfall moves nitrates down about 1 foot. If the total rainfall at one time is more than 6 inches, little nitrate will be left within the rooting depth on sands.

Between rains, some upward movement of nitrates occurs in moisture that moves toward the surface as the surface soil dries. The result is that it is difficult to predict how deep the nitrate has moved based only on cumulative rainfall.

When trying to estimate the depth of leaching of nitrates in periods of very intensive rainfall, two points need to be considered. First, the rate at which water can enter the surface of silt and clay loams may be less than the rate of rainfall, which means that much of the water runs off the surface into low spots or into creeks and ditches. Second, the soil may be saturated already. In either of these cases, the nitrates will not move down the 5 to 6 inches per inch of rain as suggested above.

Corn roots usually penetrate to 6 feet in Illinois soils. Thus, nitrates that leach only to 3 to 4 feet are well within normal rooting depth unless they reach tile lines and are drained from the field.

Nitrification Inhibitors

As Figure 11.07 shows, nitrification converts ammonium nitrogen into nitrate, the form susceptible to loss by denitrification or leaching. Use of nitrification inhibitors can retard this conversion. When inhibitors were properly applied in one experiment, as much as 42 percent of soil-applied ammonia remained in the ammonium form through the early part of the growing season, in contrast with only 4 percent that remained when inhibitors were not used. Inhibitors can therefore significantly affect crop yields. The benefit from using an inhibitor varies, however, with soil condition, time of year, type of soil, geographic location, rate of nitrogen application, and weather conditions that occur after the nitrogen is applied and before it is absorbed by the crop.

Considerable research throughout the Midwest has shown that only under wet soil conditions do inhibitors significantly increase yields. When inhibitors were applied in years of excessive rainfall, increases in corn yield ranged from 10 to 30 bushels per acre; when moisture conditions were not as conducive to denitrification or leaching, inhibitors produced no increase.

For the first 4 years of one experiment conducted by the University of Illinois, nitrification inhibitors produced no effect on grain yields because soil moisture levels were not sufficiently high. In early May of the fifth year, however, when soils were saturated with water for a long time, the application of an inhibitor in the preceding fall significantly increased corn yields (Figure 11.08). Furthermore, at a nitrogen

application rate of 150 pounds per acre, the addition of an inhibitor increased grain yields more than did the addition of another 40 pounds of nitrogen (Figure 11.08). Under the conditions of that experiment, therefore, it was more economical to use an inhibitor than to apply more nitrogen.

Because soils normally do not remain saturated with water for very long during the growing season after a sidedressing operation, the probability of benefiting from the use of a nitrification inhibitor with sidedressed nitrogen is less than from its use with either fall- or spring-applied nitrogen. Moreover, the short time between application and absorption by the crop greatly reduces the potential for nitrogen loss.

The longer the period between nitrogen application and absorption by the crop, the greater the probability that nitrification inhibitors will contribute to higher yields. The length of time, however, that fall-applied inhibitors remain effective in the soil depends partly on soil temperature. On one plot, a Drummer soil that had received an inhibitor application when soil temperature was 55°F retained nearly 50 percent of the applied ammonia in ammonium form for about 5 months. When soil temperature was 70°F, the soil retained the same amount of ammonia for only 2 months. Fall application of nitrogen with inhibitors should therefore be delayed until soil temperatures are no higher than 60°F; and though temperatures may decrease to 60°F in early September, it is advisable to delay applications until the second week of October in northern Illinois and the third week of October in central Illinois.

In general, poorly or imperfectly drained soils probably benefit the most from nitrification inhibitors. Moderately well-drained soils that undergo frequent periods of 3 or more days of flooding in the spring also benefit. Coarse-textured soils (sands) are likely to benefit more than soils with finer textures because the coarse-textured soils have a higher potential for leaching.

Time of application and geographic location must be considered along with soil type when determining whether to use a nitrification inhibitor. Employing inhibitors can significantly improve the efficiency of fall-applied nitrogen on the loams, silts, and clays of central and northern Illinois in years when the soil is very wet in the spring. At the same time, currently available inhibitors do not adequately reduce the rate of nitrification in the low-organic-matter soils of southern Illinois when nitrogen is applied in the fall for the following year's corn. The lower organic-matter content and the warmer temperatures of southern Illinois soils, both in late fall and early spring, cause the inhibitor to degrade too rapidly. Furthermore, applying an inhibitor on sandy soils in the fall does not adequately reduce nitrogen loss because the potential for leaching is too high. Fall applications of nitrogen with inhibitors thus are not recommended for sandy soils or for soils with low organic-matter content, especially those found south of Interstate 70.

In the spring, preplant applications of inhibitors may be beneficial on nearly all types of soil from which nitrogen loss frequently occurs, especially on sandy and poorly drained soils. Again, inhibitors are more likely to have an effect when subsoils are recharged with water than when they are dry at the beginning of spring.

Nitrification inhibitors are most likely to increase yields when nitrogen is applied at or below the optimum rate. When nitrogen is applied at a rate greater than that required for optimum yields, benefits from an inhibitor are unlikely, even when moisture in the soil is excessive.

Inhibitors should be viewed as soil management tools that can be used to reduce nitrogen loss. It is not safe to assume, however, that the use of a nitrification inhibitor will make it possible to reduce nitrogen rates below those currently recommended, because those rates were developed with the assumption that no significant amount of nitrogen would be lost.

Time of Nitrogen Application

For nitrogen that is fall-applied without a nitrification inhibitor, farmers in central and northern Illinois

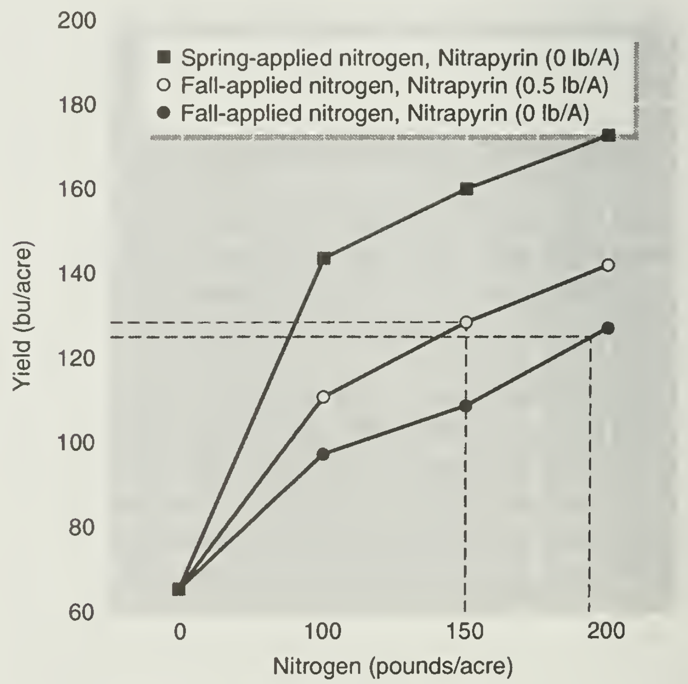

Figure 11.08. Effect of nitrification inhibitors on corn yields at varying nitrogen application rates, DeKalb.

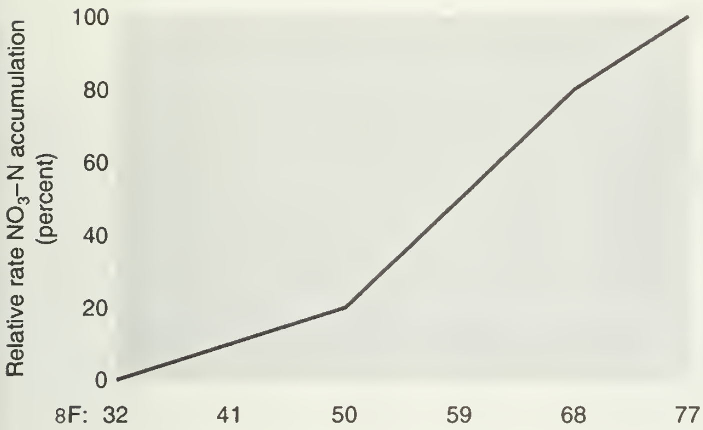

Figure 11.09. Influence of soil temperature on the relative rate of NO_3 accumulation in soils.

should apply nitrogen in non-nitrate form in the late fall after the soil temperature at 4 inches is below 50°F, except on sandy, organic, or very poorly drained soils.

The 50°F level for fall application is believed to be a realistic guideline for farmers. Applying nitrogen earlier risks too much loss (Figure 11.09). Later application risks wet or frozen fields, which would prevent application and fall tillage. Average dates on which these temperatures are reached are not satisfactory guides because of the great variability from year to year. Soil thermometers should be used to guide fall applications of nitrogen.

In Illinois, most of the nitrogen applied in late fall or very early spring is converted to nitrate by corn-planting time. Though the rate of nitrification is slow (Figure 11.09), the soil temperature is between 32°F and 40° to 45°F for a long period.

In consideration of the date at which nitrates are formed and the conditions that prevail thereafter, the difference in susceptibility to denitrification and leaching loss between late fall and early spring applications of ammonium sources is probably small. Both are, however, more susceptible to loss than is nitrogen applied at planting time or as a sidedressing.

Anhydrous ammonia nitrifies more slowly than other forms and is slightly preferred for fall applications. It is well suited to early spring application, provided the soil is dry enough for good dispersion of ammonia and closure of the applicator slit.

Sidedress application. Results collected from studies in Illinois indicated that nitrogen injected between every other row was comparable in yield to injection between every row. This finding was true irrespective of tillage system (Table 11.14) or nitrogen rate (Table 11.15). This outcome should be expected, as even with every-other-row injection, each row will have nitrogen applied on one side or the other (Figure 11.10).

Use of wider injection spacing at sidedressing allows for reduced power requirement for a given applicator width or use of a wider applicator with the same power requirement. From a practical standpoint, the lower power requirement frequently means a smaller tractor and associated smaller tire, making it easier to maneuver between rows and causing less compaction next to the row. With this system, injector positions can be adjusted to avoid placing an injector in the wheel track. When matching the driving pattern for a planter of 8, 12, 16, or 24 rows, the outside two injectors must be adjusted to half-rate application, as the injector will go between those two rows twice if one avoids having a knife in the wheel track. To avoid problems of back pressure that might be created when applying at relatively high speeds, use a double-tube knife, with two hoses going to each knife; the outside knives would require only one hose to give the half-rate application.

Winter application. Based on observations, the risk of nitrogen loss through volatilization associated with winter application of urea for corn on frozen soils is too great to consider the practice unless one is assured of at least 0.5 inch of precipitation occurring within 4

Table 11.14. Effect on Corn Yield of Ammonia Knife Spacing with Different Tillage Systems at Two Illinois Locations

	Yield (bu/A)			
Injector spacing (in.)	Plow	Chisel	Disk	No-till
DeKalb trials				
30	159	157	163	146
60	158	157	157	143
Elwood trials				
30	. . .	119	121	118
60	. . .	117	125	121

. . . = no data collected.

Table 11.15. Effect on Corn Yield of Injector Spacing of Ammonia Applied at Different Rates of Nitrogen at DeKalb

	Nitrogen (lb/A)		
Injector spacing (in.)	120	180	240
	- - - - - *yield (bu/A)* - - - - - -		
30	171	176	181
60	170	171	182

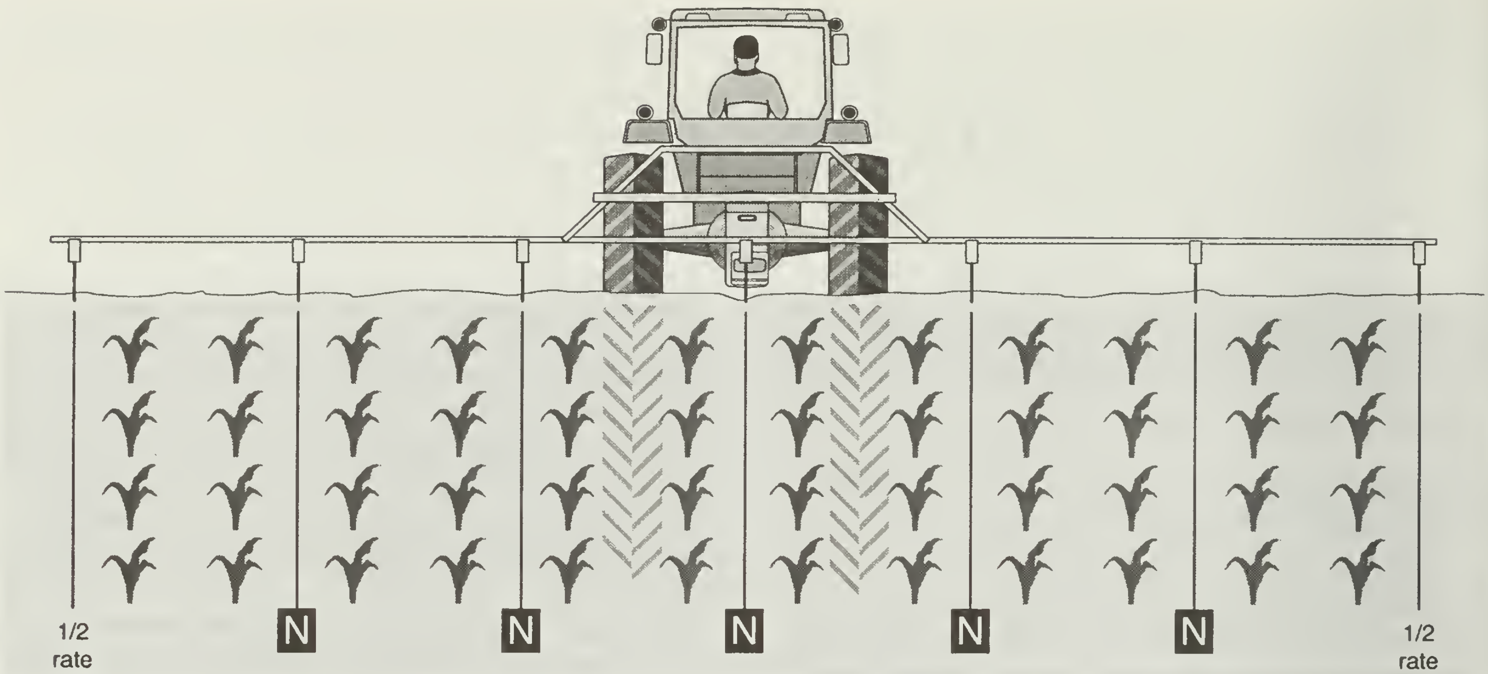

Figure 11.10. Schematic of every-other-row, sidedress nitrogen injection. The outside two injectors are set at one-half rate because the injector runs between those two rows twice.

to 5 days after application. Yield loss of 30 to 40 bushels per acre occurred when urea was surface-applied in late February to frozen soils (Table 11.16). In most years, application of urea on frozen soils has been an effective practice for wheat.

Aerial application. Under some conditions, aerial application of dry urea results in increased yield. This practice should not be considered a replacement for normal nitrogen application but rather an emergency treatment in situations where corn is too tall for normal applicator equipment. Aerial application of nitrogen solutions on growing corn is not recommended, as extensive leaf damage likely results if the application rate is greater than 10 pounds of nitrogen per acre.

Which Nitrogen Fertilizer?

Most of the nitrogen fertilizer materials available for use in Illinois provide nitrogen in the combined form of ammonia, ammonium, urea, and nitrate (Table 11.17). For many uses on a wide variety of soils, all forms are likely to produce about the same yield—provided that they are properly applied.

Ammonia. Nitrogen materials that contain free ammonia (NH_3), such as anhydrous ammonia and low-pressure solutions, must be injected into the soil to avoid loss of ammonia in gaseous form. Upon injection into the soil, ammonia quickly reacts with water to form ammonium (NH_4^+). In this positively charged form, the ion is not susceptible to gaseous loss because it is temporarily attached to the negative charges on clay and organic matter. Some of the ammonia reacts with organic matter to become a part of the soil humus.

On silt loam or soils with finer textures, ammonia moves about 4 inches from the point of injection. On more coarsely textured soils, such as sands, ammonia

Table 11.16. Effect of Source, Time, and Rate of Nitrogen Fertilizer on Corn Yield

Nitrogen treatment			Nitrogen (lb/A)			
Fertilizer material	Time of application	Method of application	0	120	180	240
			yield (bu/A)			
None (control)			89			
Urea	Winter	Surface		94	123	126
Urea	Spring	Incorporated		140	157	165
Anhydrous ammonia	Spring	Injected		149	157	158

Table 11.17. Composition of Various Nitrogen Fertilizers

Material	Total nitrogen %	Percent of total nitrogen as				Salting out temperature	Weight of solution per gallon
		Ammonia	Ammonium	Nitrate	Urea		
Anhydrous ammonia	82	100	—	—	—	—	5.90
Ammonium nitrate	34	—	50	50	—	—	—
Ammonium sulfate	21	—	100	—	—	—	—
Urea	46	—	—	—	100	—	—
Urea–ammonium nitrate	28	—	25	25	50	–1	10.70
Urea–ammonium nitrate	32	—	25	25	50	32	11.05

may move 5 to 6 inches from the point of injection. If the depth of application is shallower than the distance of movement, some ammonia may move slowly to the soil surface and escape as a gas over several days. On coarse-textured (sandy) soils, anhydrous ammonia should be placed 8 to 10 inches deep, whereas on silt-loam soils, the depth of application should be 6 to 8 inches.

Anhydrous ammonia is lost more easily from shallow placement than is ammonia in a low-pressure solution. Nevertheless, low-pressure solutions contain free ammonia and thus need to be incorporated into the soil at a depth of 2 to 4 inches.

Ammonia should not be applied to soils having a physical condition that would prevent closure of the applicator knife track. Ammonia will escape to the atmosphere whenever there is a direct opening from the point of injection to the soil surface.

Seedlings can be damaged if proper precautions are not taken when applying nitrogen materials that contain or form free ammonia. Damage may occur if nitrogen material is injected into soils that are so wet that the knife track does not close properly. If the soil dries rapidly, this track may open. Damage can also result from applying nitrogen material to excessively dry soils, which allow the ammonia to move large distances before being absorbed. Finally, damage to seedlings can be caused by using a shallower application than that suggested in the preceding paragraph. Generally, delaying planting 3 to 5 days after applying fertilizer will cause little, if any, seedling damage. While it is extremely rare, damage from fall-applied ammonia to corn seeded the next spring has been observed. The situations where this has occurred have been characterized by application in late fall on soils that were wet enough that serious compaction resulted along the side walls of the knife track. This was followed by an extremely dry winter and spring. When the surface soils dried in the spring, the soil cracked along the knife track and allowed the ammonia to escape into the seed zone.

Ammonium nitrate. Half of the nitrogen contained in ammonium nitrate is in the ammonium form, and half is in the nitrate form. The part present as ammonium attaches to the negative charges on the clay and organic-matter particles and remains in that state until it is used by the plant or converted to the nitrate ions by microorganisms present in the soil. Because 50 percent of the nitrogen is present in the nitrate form, this product is more susceptible to loss from both leaching and denitrification. Thus, ammonium nitrate should not be applied to sandy soils because of the likelihood of leaching, nor should it be applied far in advance of the time when the crop needs the nitrogen because of possible loss through denitrification.

Urea. The chemical formula for urea is $CO(NH_2)_2$. In this form, it is very soluble and moves freely up and down with soil moisture. After being applied to the soil, urea is converted to ammonia, either chemically or by the enzyme urease. The speed with which this conversion occurs depends largely on temperature. Conversion is slow at low temperatures but rapid at temperatures of 55°F or higher.

If the conversion of urea occurs on the soil surface or on the surface of crop residue or leaves, some of the resulting ammonia will be lost as a gas to the atmosphere. The potential for loss is greatest when the following conditions exist:

- Temperatures are greater than 55°F. Loss is less likely with winter or early spring applications, but results show that the loss may be substantial if the materials remain on the surface of the soil for several days.
- Considerable crop residue remains on soil surface.
- Application rates are greater than 100 pounds of nitrogen per acre.

Table 11.18. Effect of Source of Nitrogen on Yield for No-Till Corn

Nitrogen source	Application Date	Application Method	Rate (lb/A)	Yield (bu/A) at Brownstown (1974–77 avg)	Yield (bu/A) at Dixon Springs 1974	Yield (bu/A) at Dixon Springs 1975
Control			0	52	50	. . .
Ammonium nitrate	Early spring	Surface	120	96	132	160
Urea	Early spring	Surface	120	80	106	166
Ammonium nitrate	Early June	Surface	120	106	151	187
Urea	Early June	Surface	120	99	125	132

- The soil surface is moist and rapidly drying.
- Soils have a low cation-exchange capacity.
- Soils are neutral or alkaline in reaction.

Research conducted at both the Brownstown and Dixon Springs research centers has shown that surface application of urea for no-till corn did not yield as well as ammonium nitrate in most years (Table 11.18). In years when a rain was received within 1 or 2 days after application, urea resulted in as good a yield increase as did ammonium nitrate (that is, compared to results from early spring application of ammonium nitrate at Dixon Springs in 1975). In other studies, urea that was incorporated soon after application yielded as well as ammonium nitrate.

Urease inhibitor. Chemical compound N-(n-butyl) thiophosphoric triamide, commonly referred to as NBPT and sold under the trade name AgrotaiN, has been shown to inhibit the urease enzyme that converts urea to ammonia. This material can be added to urea–ammonium nitrate solutions or to urea. Addition of this material will reduce the potential for volatilization of surface-applied, urea-containing products. Experimental results collected around the Corn Belt over the last several years have shown an average increase of 4.3 bushels per acre when applied with urea and 1.6 bushels per acre when applied with urea–ammonium nitrate solutions. Where nonvolatile nitrogen treatments resulted in a higher yield than unamended urea, addition of the urease inhibitor increased yield by 6.6 bushels per acre for urea and by 2.7 bushels per acre for urea–ammonium nitrate solutions. In a year characterized by a long dry period in the spring, NBPT with urea resulted in yield increases of 20 bushels per acre as compared to urea alone in related experiments in Southern Illinois and Missouri (Tables 11.19 and 11.20). These results clearly show the importance of proper urea management techniques in years when precipitation is not received soon after surface application of urea.

Urease inhibitors have the greatest potential for benefit when urea-containing materials are surface-applied without incorporation at 50°F or higher. The potential is even greater if there is significant residue remaining on the soil surface. In situations where the urea-containing materials can be incorporated within 2 days after application, either with a tillage operation or with adequate rainfall, the potential for benefit from a urease inhibitor is very low.

Table 11.19. Effect of Nitrogen Source, Rate, and NBPT on No-Till Corn Yield in Southern Illinois

N (lb/A)	Yield (bu/A) by nitrogen source: Ammonium nitrate	Urea	Urea + NBPT
0	60	—	—
80	114	90	110
120	118	97	115
160	114	105	122

Source: Southern Illinois University, Dr. E. C. Varsa. 1992.

Table 11.20. Effect of Nitrogen Source, Rate, and NBPT on No-Till Corn Yield in Missouri

N (lb/A)	Yield (bu/A) by nitrogen source: Ammonium nitrate	Urea	Urea + NBPT
0	83	—	—
60	164	132	151
180	203	173	196

Source: University of Missouri.

Ammonium sulfate. The compound ammonium sulfate ($[NH_4]_2SO_4$) supplies all of the nitrogen in the ammonium form. As a result, it theoretically has a slight advantage over products that supply a portion of their nitrogen in the nitrate form, because the ammonium form is not susceptible to leaching or denitrification. However, this advantage is usually short-lived because all ammonium-based materials quickly convert to nitrate once soil temperatures are favorable for activity of soil organisms (above 50°F).

In contrast to urea, there is little risk of loss of the ammonium contained in ammonium sulfate through volatilization. As a result, it is an excellent material for surface application on fields that will be planted no-till that have high-residue levels. As with any other ammonium-based material, there is a risk associated with surface application in years in which there is inadequate precipitation to allow for adequate root activity in the fertilizer zone.

Ammonium sulfate is an excellent material for use on soils that may be deficient in both nitrogen and sulfur. However, applying the material at a rate sufficient to meet the nitrogen need will cause overapplication of sulfur. That is not of concern because sulfur is mobile and moves out of the profile quickly. Fortunately, there is no known environmental problem associated with sufate sulfur in water supplies.

Most ammonium sulfate available in the marketplace is a by-product of the steel, textile, or lysine industry and is marketed as either a dry granulated material or a slurry.

Ammonium sulfate is more acidifying than any of the other nitrogen materials on the market. As a rough rule, ammonium sulfate requires about 9 pounds of lime per pound of nitrogen applied, compared to 4 pounds of lime per pound of nitrogen from ammonia or urea. The extra acidity is of no concern as long as the soil is monitored for pH every 4 years.

In areas where fall application is acceptable, ammonium sulfate could be applied in late fall (after temperatures have fallen below 50°F) or in winter on frozen ground where the slope is less than 5 percent.

Nitrogen solutions. The nonpressure nitrogen solutions that contain 28 to 32 percent nitrogen consist of a mixture of urea and ammonium nitrate. Typically, half of the nitrogen is from urea, and the other half is from ammonium nitrate. The constituents of these compounds will undergo the same reactions as described earlier for the constituents applied alone.

Experiments at DeKalb have shown a yield difference between incorporated and unincorporated nitrogen solutions that were spring-applied (Table 11.21). This difference associated with method of application is probably caused by volatilization loss of some nitrogen from the surface-applied solution containing urea.

Table 11.21. Effect of Source, Method of Application, and Rate of Spring-Applied Nitrogen on Corn Yield, DeKalb

		Yield (bu/A)		
Carrier and application method	N (lb/A)	1976	1977	Avg
None	0	66	61	64
Ammonia	80	103	138	120
28% N solution, incorporated	80	98	132	115
28% N solution, unincorporated	80	86	126	106
Ammonia	160	111	164	138
28% N solution, incorporated	160	107	157	132
28% N solution, unincorporated	160	96	155	126
Ammonia	240	112	164	138
28% N solution, incorporated	240	101	164	132
28% N solution, unincorporated	240	91	153	122
$LSD_{.10}$[a]		9.1	5.2	

[a]Differences greater than the LSD value are statistically significant.

The effect on yield of postemergence application of nitrogen solutions and atrazine when corn plants are in the three-leaf stage was evaluated in Minnesota. The results indicated that yields were generally depressed when the nitrogen rate exceeded 60 pounds per acre. Leaf burn was increased by increasing the nitrogen rate, including atrazine with the nitrogen, and by hot, clear weather conditions.

Phosphorus and Potassium

Inherent Availability

Illinois has been divided into three regions in terms of the inherent phosphorus-supplying power of the soil below the plow layer in dominant soil types (Figure 11.11).

High phosphorus-supplying power means that the soil test for available phosphorus (P_1 test) is relatively high and conditions are favorable for good

root penetration and branching throughout the soil profile.

Low phosphorus-supplying power may be caused by one or more factors:

1. A low supply of available phosphorus in the soil profile because (a) the parent material was low in phosphorus; (b) phosphorus was lost in the soil-forming process; or (c) the phosphorus is made unavailable by high pH (calcareous) material.
2. Poor internal drainage that restricts root growth.
3. A dense, compact layer that inhibits root penetration or branching.
4. Shallowness to bedrock, sand, or gravel.
5. Droughtiness, strong acidity, or other conditions that restrict crop growth and reduce rooting depth.

Regional differences in phosphorus-supplying power are shown in Figure 11.11. Parent material and degree of weathering were the primary factors considered in determining the various regions.

The "high" region is in western Illinois, where the primary parent material was more than 4 to 5 feet of loess that was high in phosphorus content. The soils are leached of carbonates to a depth of more than 3½ feet, and roots can spread easily in the moderately permeable profiles.

The "medium" region is in central Illinois, with arms extending into northern and southern Illinois. The primary parent material was more than 3 feet of loess over glacial till, glacial drift, or outwash. Some sandy areas with low phosphorus-supplying power occur in the region. In comparison with the high-phosphorus region, more of the soils are poorly drained and have less available phosphorus in the subsoil and substratum horizons. Carbonates are likely to occur at shallower depths than in the "high" region. The soils in the northern and central areas are generally free of root restrictions, whereas soils in the southern arm are more likely to have root-restricting layers within the profile. The phosphorus-supplying power of soils of the region is likely to vary with natural drainage. Soils with good internal drainage are likely to have higher levels of available phosphorus in the subsoil and substratum. If internal drainage is fair or poor, phosphorus levels in the subsoil and substratum are likely to be low or medium.

In the "low" region in southeastern Illinois, the soils were formed from 2½ to 7 feet of loess over weathered Illinoisan till. The profiles are more highly weathered than in the other regions and are slowly or very slowly permeable. Root development is more restricted than in the "high" or "medium" regions. Subsoil levels of phosphorus may be rather high by soil test in some soils of the region, but this is partially offset by conditions that restrict rooting.

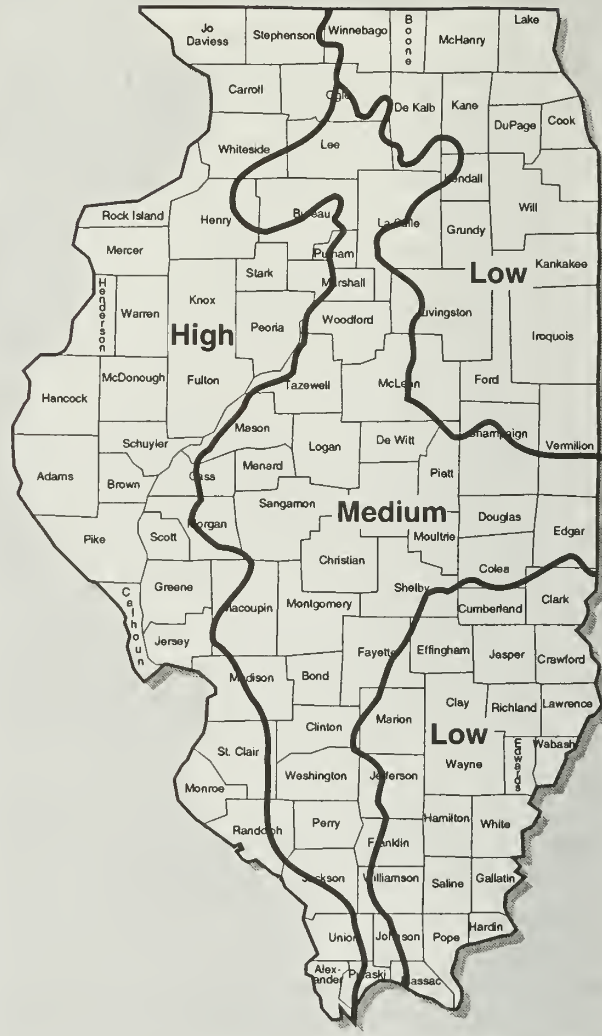

Figure 11.11. Subsoil phosphorus-supplying power in Illinois.

In the "low" region in northeastern Illinois, the soils were formed from thin loess (less than 3 feet) over glacial till. The glacial till, generally low in available phosphorus, ranges in texture from gravelly loam to clay in various soil associations of the region. In addition, shallow carbonates further reduce the phosphorus-supplying power of the soils of the region. Further, high bulk density and slow permeability in the subsoil and substratum restrict rooting in many soils of the region.

The three regions are delineated to show broad differences among them. Parent material, degree of weathering, native vegetation, and natural drainage vary within a region and cause variation in the soil's phosphorus-supplying power. It appears, for ex-

ample, that soils developed under forest cover have more available subsoil phosphorus than those developed under grass.

Illinois is divided into two general regions for potassium, based on cation-exchange capacity (Figure 11.12). Important differences exist, however, among soils within these general regions because of differences in these factors:

1. The amount of clay and organic matter, which influences the exchange capacity of the soil.
2. The degree of weathering of the soil material, which affects the amount of potassium that has been leached out.
3. The kind of clay mineral.
4. Drainage and aeration, which influence uptake of potassium.
5. The parent material from which the soil was formed.

Soils with a cation-exchange capacity less than 12 meq/100 grams are classified as having low capacity. These soils include the sandy soils because minerals from which they were developed are inherently low in potassium. Sandy soils also have very low cation-exchange capacities and thus do not hold much reserve potassium.

Silt-loam soils in the "low" area in southern Illinois (claypans) are relatively older in terms of soil development; consequently, much more of the potassium has been leached out of the rooting zone. Furthermore, wetness and a platy structure between the surface and subsoil may interfere with rooting and with potassium uptake early in the growing period, even though roots are present.

Figure 11.12. Cation-exchange capacity of Illinois soils. The shaded areas are sands with low cation-exchange capacity.

Rate of Fertilizer Application

Minimum soil-test levels required to produce optimum crop yields vary depending on the crop to be grown and the soil type (Figures 11.13 and 11.14). Near-maximum yields of corn and soybeans are obtained when levels of available phosphorus are maintained at 30, 40, and 45 pounds per acre for soils in the high, medium, and low phosphorus-supplying regions, respectively. Potassium soil-test levels at which optimum yields of these two crops are attained are 260 and 300 pounds of exchangeable potassium per acre for soils in the low and high cation-exchange capacity regions, respectively. Because phosphorus, and on most soils also potassium, will not be lost from the soil system other than through crop removal or soil erosion and because these are minimum values required for optimum yields, it is recommended that soil-test levels be built up to 40, 45, and 50 pounds per acre of phosphorus for soils in the high, medium, and low phosphorus-supplying regions, respectively.

Depending on the soil-test level, the amount of fertilizer recommended may be buildup plus maintenance, maintenance, or no fertilizer. The buildup is the amount of material required to increase the soil test to the desired level. The maintenance addition is the amount required to replace the amount that will be removed by the crop to be grown.

Buildup plus maintenance. When soil-test levels are below the desired values, it is suggested that enough fertilizer be added to build the test to the desired goal and to replace what the crop will remove. At these test levels, the yield of the crop will be affected by the amount of fertilizer applied that year.

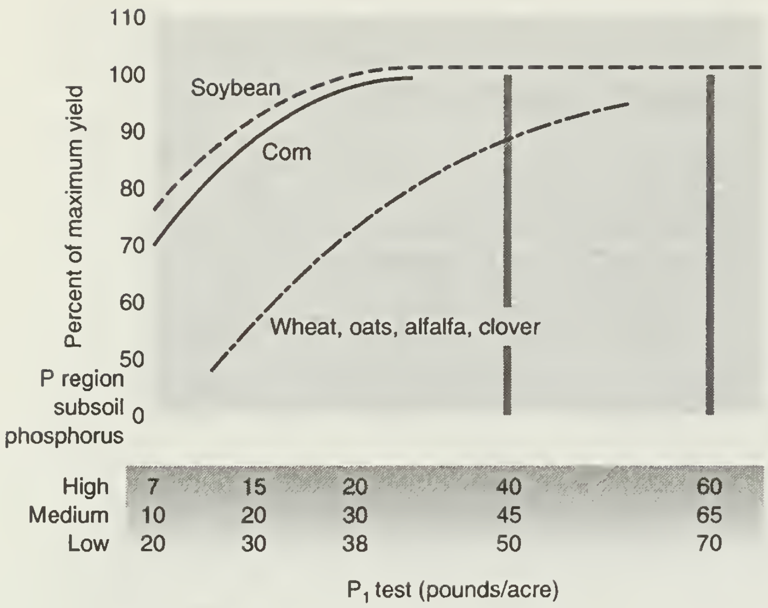

Figure 11.13. Relationship between expected yield and soil-test phosphorus.

Maintenance. When the soil-test levels are between the minimum and 20 pounds above the minimum for phosphorus (that is, 40 to 60, 45 to 65, or 50 to 70) or between the minimum and 100 pounds above the minimum for potassium (260 to 360 or 300 to 400), apply enough to replace what the crop to be grown is expected to remove. The yield of the current crop may not be affected by the fertilizer addition, but the yield of subsequent crops will be adversely affected if the materials are not applied to maintain soil-test levels.

No fertilizer. Although it is recommended that soil-test levels be maintained slightly above the level at which optimum yield would be expected, it would not be economical to attempt to maintain excessively high values. *Therefore, it is suggested that no phosphorus be applied if* P_1 *values are higher than 60, 65, and 70 for soils in the high, medium, and low phosphorus-supplying regions, respectively. No potassium is suggested if test levels are above 360 and 400 for the low and high cation-exchange capacity regions, unless crops that remove large amounts of potassium (such as alfalfa or corn silage) are being grown.* When soil-test levels are between 400 and 600 pounds per acre of potassium and corn silage or alfalfa is being grown, the soil should be tested every 2 years instead of every 4, or maintenance levels of potassium should be added to ensure that soil-test levels do not fall below the point of optimum yields.

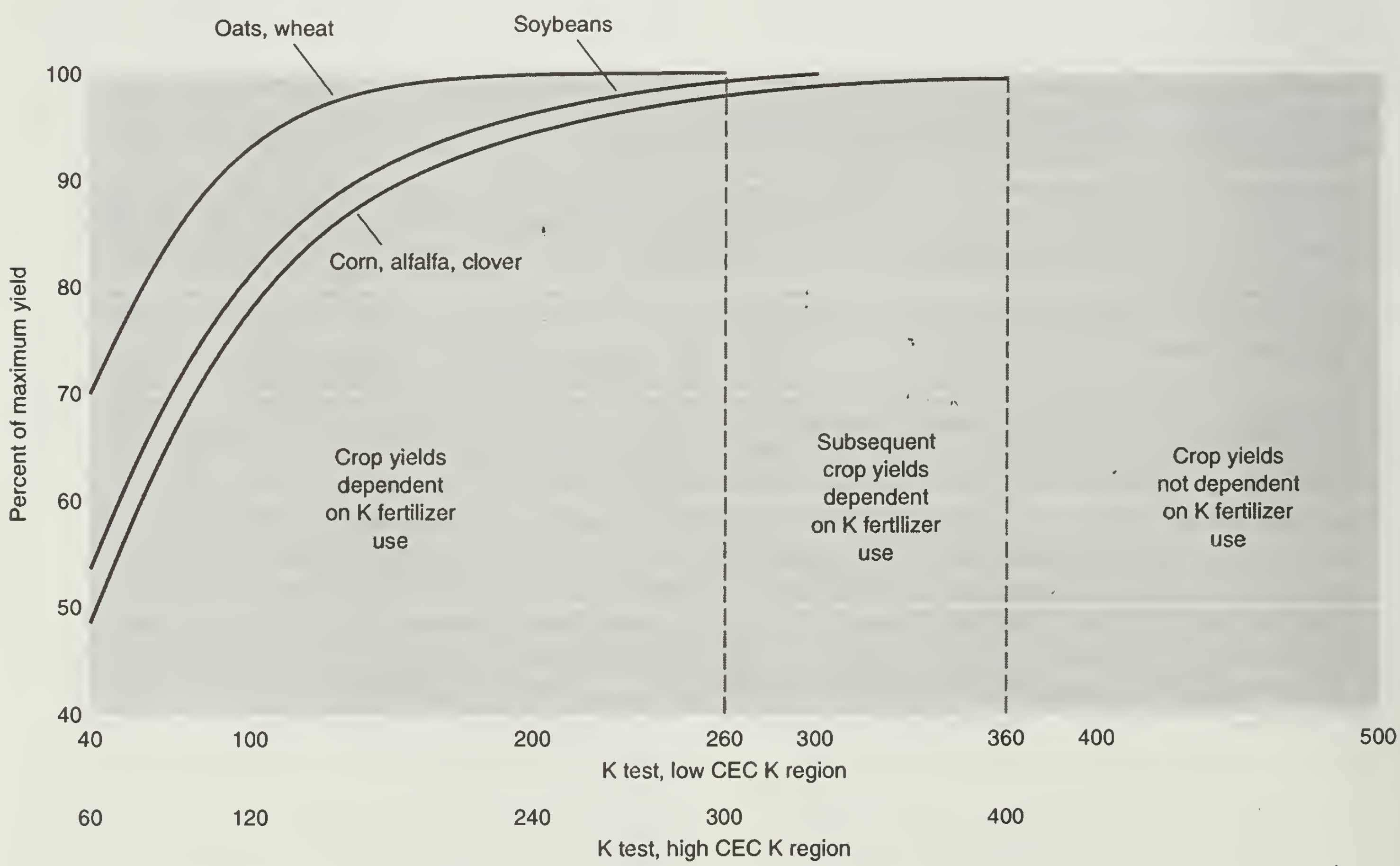

Figure 11.14. Relationship between expected yield and soil-test potassium.

Consequences of omitting fertilizer. The impact of eliminating phosphorus or potassium fertilizer on yield and soil-test level will depend on the initial soil test and the number of years that applications are omitted. In a recent Iowa study, elimination of phosphorus application for 9 years decreased soil-test levels from 136 to 52 pounds per acre, but yields were not adversely affected in any year as compared to plots where soil-test levels were maintained (Figure 11.15). In the same study, elimination of phosphorus for the 9 years when the initial soil test was 29 resulted in a decrease in soil-test level to 14 and a decrease in yield to 70 percent of the yield obtained when adequate fertility was supplied. Elimination of phosphorus at an intermediate soil-test level had little impact on yield but decreased the soil-test level from 67 to 26 pounds per acre over the 9 years. These as well as similar Illinois results indicate little if any potential for a yield decrease if phosphorus application was eliminated for 4 years on soils that have a phosphorus test of 60 pounds per acre or higher.

PHOSPHORUS

Buildup. Research has shown that, as an average for Illinois soils, 9 pounds of P_2O_5 per acre is required to increase the P_1 soil test by 1 pound. The recommended rate of buildup phosphorus is thus nine times the difference between the soil-test goal and the actual soil-test value. The amount of phosphorus recommended for buildup over 4 years for various soil-test levels is presented in Table 11.22.

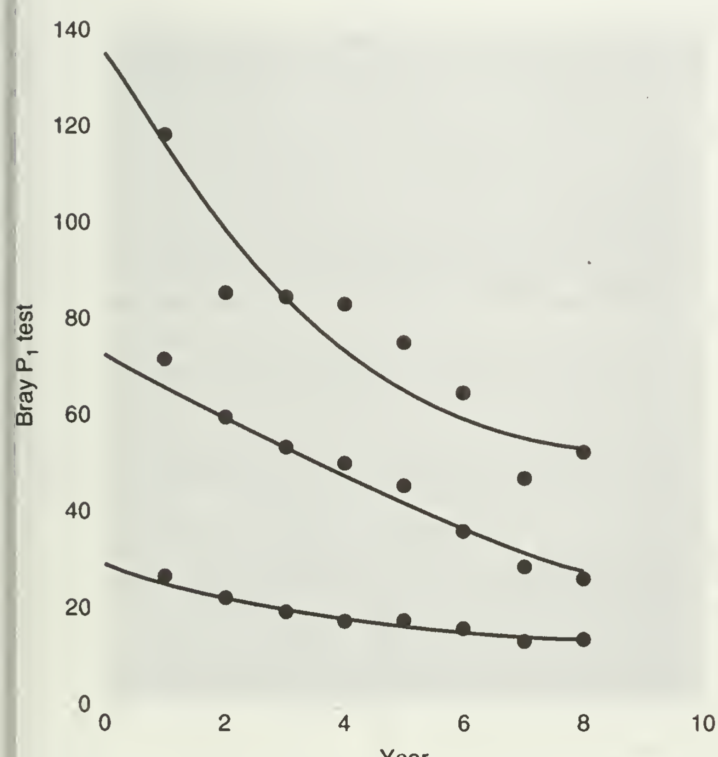

Figure 11.15. Effect of elimination of P fertilizer on P_1 soil test.

Table 11.22. Amount of Phosphorus (P_2O_5) Required to Build Up the Soil

P_1 test (lb/A)	Lb/A of P_2O_5 to apply each year for soils with supplying power rated		
	Low	Medium	High
4	103	92	81
6	99	88	76
8	94	83	72
10	90	79	68
12	86	74	63
14	81	70	58
16	76	65	54
18	72	61	50
20	68	56	45
22	63	52	40
24	58	47	36
26	54	43	32
28	50	38	27
30	45	34	22
32	40	29	18
34	36	25	14
36	32	20	9
38	27	16	4
40	22	11	0
42	18	7	0
44	14	2	0
45	11	0	0
46	9	0	0
48	4	0	0
50	0	0	0

NOTE: Amounts are based on buildup over 4 years. Nine pounds of P_2O_5 per acre are required to change the P_1 soil test 1 pound.

Because the 9-pound rate is an average for Illinois soils, some soils will fail to reach the desired goal in 4 years with P_2O_5 applied at this rate, and others will exceed the goal. It is recommended that each field be retested every 4 years.

In addition to the supplying power of the soil, the crop to be grown influences the optimum soil-test value. For example, the phosphorus soil-test level required for optimum yields of wheat and oats (Figure 11.13) is considerably higher than that required for corn and soybean yields, partly because wheat

Table 11.23. Maintenance Fertilizer Required for Various Crop Yields

Yield per acre	P_2O_5 (lb/A)	K_2O[a] (lb/A)	Yield per acre	P_2O_5 (lb/A)	K_2O[a] (lb/A)
Corn grain (bu)			**Corn silage (bu; tons)**		
90	39	25	90; 18	48	126
100	43	28	100; 20	53	140
110	47	31	110; 22	58	154
120	52	34	120; 24	64	168
130	56	36	130; 26	69	182
140	60	39	140; 28	74	196
150	64	42	150; 30	80	210
160	69	45			
170	73	48	**Wheat (bu)**	27[b]	9
180	77	50	30	36	12
190	82	53	40	45	15
200	86	56	50	54	18
			60	63	21
Oats (bu)			70	72	24
50	19[b]	10	80	81	27
60	23	12	90	90	30
70	27	14	100	99	33
80	30	16	110		
90	34	18			
100	38	20	**Alfalfa, grass,**		
110	42	22	**or alfalfa-grass**		
120	46	24	**mixtures (tons)**		
130	49	26	2	24	100
140	53	28	3	36	150
150	57	30	4	48	200
			5	60	250
Soybeans (bu)			6	72	300
30	26	39	7	84	350
40	34	52	8	96	400
50	42	65	9	108	450
60	51	78	10	120	500
70	60	91			
80	68	104			
90	76	117			
100	85	130			

[a] If annual application is chosen, potassium application will be 1.5 times the values shown.
[b] Values given are 1.5 times actual P_2O_5 removal for wheat and oats.

and corn have different phosphorus uptake patterns. Wheat requires a large amount of readily available phosphorus in the fall, when the root system is feeding primarily from the upper soil surface. Phosphorus is taken up by corn until the grain is fully developed, so subsoil phosphorus is more important in interpreting the phosphorus test for corn than for wheat. *To compensate for the higher phosphorus requirements of wheat and oats, it is suggested that 1.5 times the amount of expected phosphorus removal be applied prior to seeding these crops. This correction has already been included in the maintenance values listed for wheat and oats in Table 11.23.*

Maintenance. In addition to adding fertilizer to build up the soil test, add sufficient fertilizer each year to maintain a specified soil-test level. The amount of fertilizer required to maintain the soil-test value is the amount removed by the harvested portion of the crop (Table 11.23). The only exception to this guideline is that the maintenance value for wheat and oats is 1.5 times the amount of phosphorus (P_2O_5) removed by the grain. This correction has already

been accounted for in the maintenance values given in Table 11.23.

Potassium

As indicated, phosphorus usually remains in the soil unless it is removed by a growing crop or by erosion; thus soil levels can be built up as described. Experience during recent years indicates that on most soils potassium tends to follow the buildup pattern of phosphorus, but on other soils, soil-test levels do not build up as expected. Because of this, options for both buildup plus maintenance and annual application are provided.

Producers whose soils have one or more of the following conditions should consider annual application:

1. Soils for which past records indicate that soil-test potassium does not increase when buildup applications are applied.
2. Sandy soils that do not have a capacity large enough to hold adequate amounts of potassium.
3. Agricultural lands having an unknown or a very short tenure arrangement.

On all other fields, buildup plus maintenance is suggested.

Rate of Fertilizer Application

Buildup. The only significant loss of soil-applied potassium is through crop removal or soil erosion. It is thus recommended that soil-test potassium be built up to values of 260 and 300 pounds of exchangeable potassium for soils in the low and high cation-exchange capacity region, respectively. These values are slightly higher than that required for maximum yield, but as in the recommendations for phosphorus, this will ensure that potassium availability will not limit crop yields (Figure 11.14).

Research has shown that 4 pounds of K_2O is required on average to increase the soil test by 1 pound. Therefore, the recommended rate of potassium application for increasing the soil-test value to the desired goal is four times the difference between the soil-test goal and the actual value of the soil test.

Tests on soil samples that are taken before May 1 or after September 30 should be adjusted downward as follows: subtract 30 for the dark-colored soils in central and northern Illinois; subtract 45 for the light-colored soils in central and northern Illinois and for fine-textured bottomland soils; subtract 60 for the medium- and light-colored soils in southern Illinois. Annual rates of buildup of potassium application

Table 11.24. Amount of Potassium (K_2O) Required to Build Up the Soil

	Lb/A of K_2O to apply each year for soils with cation-exchange capacity rated	
K test[a] (lb/A)	Low (< 12 meq/100 g soil)	High (≥ 12 meq/100 g soil)
50	210	250
60	200	240
70	190	230
80	180	220
90	170	210
100	160	200
110	150	190
120	140	180
130	130	170
140	120	160
150	110	150
160	100	140
170	90	130
180	80	120
190	70	110
200	60	100
210	50	90
220	40	80
230	30	70
240	20	60
250	10	50
260	0	40
270	0	30
280	0	20
290	0	10
300	0	0

NOTE: Amounts are based on buildup over 4 years. Four pounds of K_2O per acre are required to change the potassium test 1 pound.

[a]Tests on soil samples taken before May 1 or after September 30 should be adjusted downward:

Subtract 30 pounds for dark-colored soils in central and northern Illinois.

Subtract 45 pounds for light-colored soils in central and northern Illinois and for fine-textured bottomland soils.

Subtract 60 pounds for medium- and light-colored soils in southern Illinois.

recommended for a 4-year period for various soil-test values are presented in Table 11.24.

Wheat is not very responsive to potassium unless the soil-test value is less than 100. Because wheat is usually grown in rotation with corn and soybeans, it is suggested that the soils be maintained at the optimum available potassium level for corn and soybeans.

Maintenance. As with phosphorus, the amount of fertilizer required to maintain the soil-test value equals the amount removed by the harvested portion of the crop (Table 11.23).

Annual application. If soil-test levels are below the desired buildup goal, apply potassium fertilizer annually at an amount 1.5 times the potassium content in the harvested portion of the expected yield. If levels are only slightly below desired buildup levels, so that buildup and maintenance are less than 1.5 times removal, add the lesser amount. Continue to monitor the soil-test potassium level every 4 years.

If soil-test levels are within a range from the desired goal to 100 pounds above the desired potassium goal, apply enough potassium fertilizer to replace what the harvested yield will remove.

Buildup plus maintenance and annual application each have advantages and disadvantages. In the short run, the annual option will likely be less costly. In the long run, the buildup approach may be more economical. In years of high income, tax benefits may be obtained by applying high rates of fertilizer. Also, in periods of low fertilizer prices, the soil can be built to higher levels that in essence bank the materials in the soil for use at a later date when fertilizer prices are higher. Producers using the buildup system are insured against yield loss that may occur in years when weather conditions prevent fertilizer application or in years when fertilizer supplies are not adequate. The primary advantage of the buildup concept is the slightly lower risk of potential yield reduction that may result from lower annual fertilizer rates. This is especially true in years of exceptionally favorable growing conditions. The primary disadvantage of the buildup option is the high cost of fertilizer in the initial buildup years.

Examples of how to figure phosphorus and potassium fertilizer recommendations follow.

Example 1. Continuous corn with a yield goal of 140 bushels per acre:

(a) *Soil-test results*

Soil-test results	*Soil region*
P_1 30	High
K 250	High

(b) *Fertilizer recommendation (lb/A/year)*

	P_2O_5	K_2O
Buildup	22 (Table 11.22)	50 (Table 11.24)
Maintenance	60 (Table 11.23)	39 (Table 11.23)
Total	82	89

Example 2. Corn-soybean rotation with a yield goal of 140 bushels per acre for corn and 40 bushels per acre for soybeans:

(a) *Soil-test results*

Soil-test results	*Soil region*
P_1 20	Low
K 200	Low

(b) *Fertilizer recommendation (lb/A/year)*

	P_2O_5	K_2O
	Corn	
Buildup	68	60
Maintenance	60	39
Total	128	99
	Soybeans	
Buildup	68	60
Maintenance	34	52
Total	102	112

Note that buildup recommendations are independent of the crop to be grown, but maintenance recommendations are directly related to the crop to be grown and the yield goal for the particular crop.

Example 3. Continuous corn with a yield goal of 150 bushels per acre:

(a) *Soil-test results*

Soil-test results	*Soil region*
P_1 90	Low
K 420	Low

(b) *Fertilizer recommendation (lb/A/year)*

	P_2O_5	K_2O
Buildup	0	0
Maintenance	0	0
Total	0	0

Note that soil-test values are higher than those suggested; thus no fertilizer is recommended. Retest the soil after 4 years to determine fertility needs.

Example 4. Corn-soybean rotation with a yield goal of 120 bushels per acre for corn and 35 bushels per acre for soybeans:

(a)

Soil-test results	*Soil region*
P_1 20	Low
K 180	Low (soil test does not increase as expected)

(b) *Fertilizer recommendation (lb/A/year)*

	P_2O_5	K_2O
	Corn	
Buildup	68	. . .
Maintenance	52	. . .
Total	120	51 (34 x 1.5)
	Soybeans	
Buildup	68	. . .
Maintenance	30	. . .
Total	98	69 (46 x 1.5)

For farmers planning to double-crop soybeans after wheat, it is suggested that phosphorus and potassium fertilizer required for both the wheat and soybeans be applied before seeding the wheat. This practice reduces the number of field operations at planting time and hastens the planting operation.

The maintenance recommendations for phosphorus and potassium in a double-crop wheat and soybean system are presented in Tables 11.25 and 11.26, respectively. Assuming a wheat yield of 50 bushels per acre followed by a soybean yield of 30 bushels per acre, the maintenance recommendation would be 71 pounds of P_2O_5 and 54 pounds of K_2O per acre.

Computerized Recommendations

Soil fertility recommendations have been incorporated into a microcomputer program that utilizes the soil-test information, soil type and characteristics, cropping and management history, cropping plans, and yield goals to develop recommendations for lime, nitrogen, phosphorus, and potassium. This program, called *Soil Plan*, groups similar fertilizer recommendations and provides a map showing where each recommendation should be implemented within the field. The user can alter the map to show the desired spread pattern. The program also indicates the potential impact of altering the recommendation on crop yield.

Table 11.25. Maintenance Phosphorus Required for Wheat–Soybean Double-Crop System

Wheat yield (bu/A)	Lb/A of P_2O_5 required for desired soybean yield (bu/A)				
	20	30	40	50	60
30	44	53	61	69	78
40	53	62	70	78	87
50	62	71	79	87	96
60	71	80	88	96	105
70	80	89	97	105	114
80	89	98	106	114	123

Further information about this program may be obtained from IlliNet Software, 548 Bevier Hall, 905 S. Goodwin Avenue, Urbana, IL 61801.

Time of Application

Although the fertilizer rates for buildup and maintenance in Tables 11.22 through 11.24 are for an annual application, producers may apply enough nutrients in any 1 year to meet the needs of the crops to be grown in the succeeding 2 to 3 years.

Phosphorus and potassium fertilizers may be applied in the fall to fields that will not be fall-tilled, provided that the slope is less than 5 percent. Do not fall-apply fertilizer to fields that are subject to rapid runoff. When the probability of runoff loss is low, soybean stubble need not be tilled solely for the purpose of incorporating fertilizer. *This statement holds true when ammoniated phosphate materials are used as well because the potential for volatilization of nitrogen from ammoniated phosphate materials is insignificant.*

For perennial forage crops, broadcast and incorporate all of the buildup and as much of the maintenance phosphorus as economically feasible before seeding. On soils with low fertility, apply 30 pounds of phosphate (P_2O_5) per acre using a band seeder. Using a band seeder, it is safe to apply a maximum of 30 to 40 pounds of potash (K_2O) per acre in the band with the phosphorus. Up to 600 pounds of K_2O per acre can be safely broadcast in the seedbed without damaging seedlings.

Applications of phosphorus and potassium topdressed on perennial forage crops may be made at any convenient time. Usually this will be after the first harvest or in September.

Table 11.26. Maintenance Potassium Required for Wheat–Soybean Double-Crop System

Wheat yield (bu/A)	Lb/A of K_2O required for desired soybean yield (bu/A)				
	20	30	40	50	60
30	35	48	61	74	87
40	38	51	64	77	90
50	41	54	67	80	93
60	44	57	70	83	96
70	47	60	73	86	99
80	50	63	76	89	102

High Water Solubility of Phosphorus

The water solubility of the P_2O_5 listed as available on the fertilizer label is of little importance under typical field crop and soil conditions on soils with medium to high levels of available phosphorus when recommended rates of application and broadcast placement are used. Due to rapid interaction of phosphorus fertilizer with iron and aluminum, phosphorus is tightly bound in the soil such that water solubility does not imply great movement or leaching.

For some situations, water solubility is important:

1. For band placement of a small amount of fertilizer to stimulate early growth, at least 40 percent of the phosphorus should be water-soluble for application to acidic soils and, preferably, 80 percent for calcareous soils. As shown in Table 11.27, the phosphorus in nearly all fertilizers commonly sold in Illinois is highly water-soluble. Phosphate water solubility above 80 percent has not been shown to increase yield any farther than water solubility of at least 50 percent.
2. For calcareous soils, a high degree of solubility in water is desirable, especially on soils that are shown by soil test to be low in available phosphorus.

Phosphorus and the Environment

Phosphorus has been identified as an important pollutant to surface waters. At very low concentrations, it can increase eutrophication of lakes and streams, which leads to problems with their use for fisheries, recreation, industry, and drinking water. Although eutrophication is the natural aging process of lakes and streams, human activities can accelerate this process by increasing the concentration of nutrients flowing into water systems. Since phosphorus is the element most often limiting eutrophication in natural water bodies, controlling its input into lakes and streams is very important. At the present time, there are no established criteria for phosphorus in water. The United States Environmental Protection Agency is in the process of developing a strategy to adopt nutrient criteria as part of state water quality standards.

There are concerns that agricultural runoff and erosion from soils may be major contributors to eutrophication. While this loss may not be of economic significance to farmers, it may create economic impacts on water quality. Even though phosphorus loss from agricultural fields may not be of economic significance and even though there are no standards established for phosphorus runoff, it is in the best interest of all in agriculture to minimize the amount of phosphorus loss. While additional research will likely lead to new and better ways to minimize phosphorus loss, the following practices are already known to help:

1. Do not maintain excessively high phosphorus soil test levels. Research has demonstrated that the higher the soil-test level, the greater the loss of dissolved phosphorus (Figure 11.16). This relationship does vary somewhat depending on soil type. Environmental decisions regarding phosphorus applications should not be made solely on phosphorus soil-test levels. Rather, the decision should also include such factors as distance from a significant lake or stream, infiltration rate, slope, and residue cover. Additional work is being done to develop a system that more accurately predicts the vulnerability to phosphorus loss on a field-by-field basis. At this time, the research database is inadequate to establish a soil-test level that can be used for environmental purposes. Soil-test procedures were designed to predict where phosphorus was needed;

Table 11.27. Water Solubility of Some Common Processed-Phosphate Materials

Material	Percent P_2O_5	Percent water-soluble
Ordinary superphosphate 0-20-0	16–22	78
Triple superphosphate	44–47	84
Mono-ammonium phosphate 11-48-0	46–48	100
Diammonium phosphate 18-46-0	46	100
Ammonium polyphosphate 10-34-0, 11-37-0	34–37	100

Table 11.28. Suggested Soil-Test Levels for Secondary Nutrients

Soil type	Levels adequate for crop production (lb/A) Calcium	Magnesium	Rating	Sulfur (lb/A)
Sandy	400	60–75	Very low	0–12
Silt loam	800	150–200	Low	12–22
			Response unlikely	22

they were not designed to predict environmental problems. One possible problem with using soil-test values to predict environmental problems is in sample depth. Normally samples are collected to a 7-inch depth for prediction of nutritional needs. For environmental purposes, it would often be better to collect the samples from a 1- or 2-inch depth, which is the depth that will influence phosphorus runoff. Another potential problem is within field soil-test level variability in relation to the dominant runoff and sediment-producing zones.

2. Maintain buffer strips at the point where water leaves the field.
3. Minimize erosion. Although this may not reduce the potential for loss of dissolved phosphorus, it will reduce the potential for loss of total phosphorus.
4. Match nutrient applications to crop needs. This will minimize the potential for excessive buildup of phosphorus soil tests and reallocate phosphorus sources to fields or areas where they can produce agronomic benefits.
5. Where possible, grow high-yielding, high-phosphorus-removing crops on fields that have excessively high soil-test phosphorus levels. Even when this is done, it may take several years to reduce very high soil-test levels to medium to high tests.

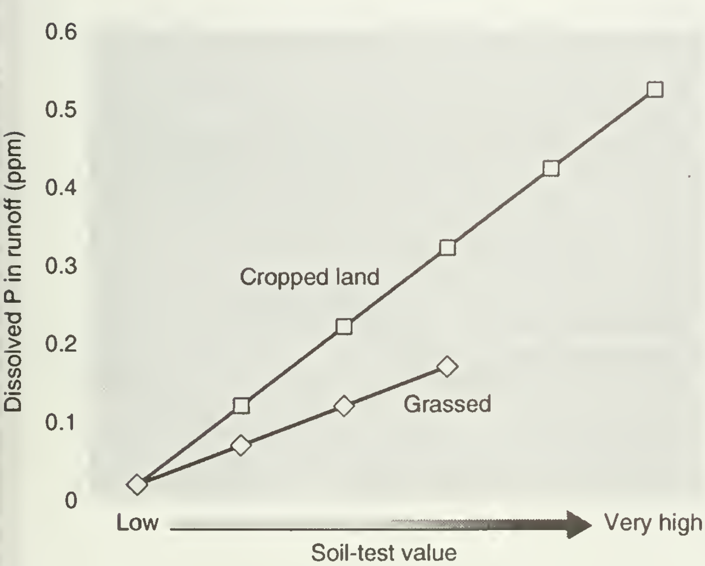

Figure 11.16. Relationship between soil-test value and dissolved phosphorus in runoff.

Table 11.29. Average Yields at Responding and Nonresponding Zinc and Sulfur Test Sites, 1977–79

	Sites	Yield from untreated plots (bu/A)	Yield from zinc-treated plots (bu/A)	Yield from sulfur-treated plots (bu/A)
Responding sites				
Low-sulfur soil	5	140.0	. . .	151.2
Low-zinc soil	3	150.6	164.7	. . .
Nonresponding sites	80	147.6	146.2	148.2

Secondary Nutrients

The elements classified as secondary nutrients include calcium, magnesium, and sulfur. Crop yield response to application of these three nutrients has been observed on a very limited basis in Illinois. The database necessary to correlate and calibrate soil-test procedures is thus limited, and the reliability of the suggested soil-test levels for the secondary nutrients presented in Table 11.28 is low.

Deficiency of calcium has not been seen in Illinois where soil pH is 5.5 or higher. Calcium deficiency associated with acidic soils should be corrected by using limestone that is adequate to correct the soil pH.

Magnesium deficiency has been recognized in isolated situations in Illinois. Although the deficiency is usually associated with acidic soils, in some instances low magnesium has been reported on sandy soils that were not excessively acidic. The soils most likely to be deficient in magnesium include sandy soils throughout Illinois and low exchange-capacity soils of southern Illinois. Deficiency will be more likely where calcitic rather than dolomitic limestone has been used.

Sulfur deficiency has been reported with increasing frequency throughout the Midwest. Deficiencies

probably are occurring because of (1) increased use of sulfur-free fertilizer; (2) decreased use of sulfur as a fungicide and insecticide; (3) increased crop yields, resulting in increased requirements for all of the essential plant nutrients; and (4) decreased atmospheric sulfur supply. Early season sulfur symptoms may disappear as rainfall contributes some sulfur and as root systems develop to exploit greater soil volume.

Organic matter is the primary source of sulfur in soils, so soils low in organic matter are more likely to be deficient than soils high in organic matter. Because sulfur is very mobile and can be readily leached, deficiency is more likely on sandy soils than on finer-textured soils.

A yield response to sulfur application was observed at 5 of 85 locations in Illinois (Table 11.29). Two of these responding sites, one an eroded silt loam and one a sandy soil, were found in northwestern Illinois (Whiteside and Lee counties); one site, a silty clay loam, was in central Illinois (Sangamon County); and two sites, one a silt loam and one a sandy loam, were in southern Illinois (Richland and White counties).

At the responding sites, sulfur treatments resulted in corn yields that averaged 11.2 bushels per acre more than yields from the untreated plots. At the nonresponding sites, yields from the sulfur-treated plots averaged only 0.6 bushel per acre more than those from the untreated plots (Table 11.29). If only the responding sites are considered, the sulfur soil test predicts with good reliability which sites will respond to sulfur applications. Of the five responding sites, one had only 12 pounds of sulfur per acre, less than the amount considered necessary for normal plant growth, and three had marginal sulfur concentration (from 12 to 20 pounds of sulfur per acre). Sulfur tests on the 80 nonresponding sites showed 14 to be deficient and 29 to have a sulfur level considered marginal for normal plant growth. Sulfur applications, however, produced no significant positive responses in these plots. The correlation between yield increases and measured sulfur levels in the soil was very low, indicating that the sulfur soil test did not reliably predict sulfur need.

Experiments were conducted over 2 years on a Cisne silt loam and a Grantsburg silt loam in southern Illinois to evaluate the effect of sulfur application on wheat production. Even though increasing rates of sulfur application increased the sulfur concentration of the flag leaf and the whole plant, it did not increase grain yield at either location in either year. Based on these studies, routine application of sulfur fertilizer for wheat production does not appear warranted.

In addition to evaluating soil-test values, consider organic-matter level, potential atmospheric sulfur contributions, subsoil sulfur content, and moisture conditions just before soil sampling in determining whether a sulfur response is likely. If organic matter exceeds 2.5 percent or if the field in question is downwind from industrial operations where significant sulfur is emitted, use sulfur only on a trial basis even when the soil-test reading is low. Because sulfur is a mobile nutrient supplied principally by organic-matter oxidation, abnormal precipitation (either high or low) could adversely affect the sulfur status of samples taken from the soil surface. If precipitation has been high just before sampling, some samples may have a low reading due to leaching. If precipitation were low and temperatures warm, some soils might have a high reading when, in fact, the soil is not capable of supplying adequate sulfur throughout the growing season.

Table 11.30. Suggested Soil-Test Levels for Micronutrients

Micronutrient and procedure	Soil-test level (lb/A)		
	Very low	Low	Adequate
Boron (hot-water soluble)	0.5	1	2
Iron (DTPA)	. . .	< 4	> 4
Manganese (DTPA)	. . .	< 2	> 2
Manganese (H_3PO_4)	. . .	< 10	> 10
Zinc (.1N HCl)	. . .	< 7	> 7
Zinc (DTPA)	. . .	< 1	> 1

Table 11.31. Effect of Time of Application of Manganese on Soybean Yield

Treatment			
Manganese (lb/A/application)	Application		Yield (bu/A)
	Times	Dates	
0	—	—	56
0.15	1	6–19	63
0.15	1	7–2	66
0.15	1	7–17	66
0.15	2	6–19, 7–2	69
0.15	3	6–19, 7–2, 7–19	71

Micronutrients

The elements classified as essential micronutrients include zinc, iron, manganese, copper, boron, molybdenum, and chlorine. These elements are classified as micronutrients because they are required in small (micro) amounts. Confirmed deficiencies of any of these micronutrients in Illinois have been limited to boron deficiency of alfalfa, zinc deficiency of corn, and iron and manganese deficiencies of soybeans.

Similar to the tests for secondary nutrients, micronutrient tests have very low reliability and usefulness because of the limited database available to correlate and calibrate the tests. Suggested levels for each test are provided in Table 11.30. In most cases, micronutrient plant analysis will probably provide a better estimate of micronutrient needs than the soil test.

Manganese deficiency (stunted plants with green veins in yellow or whitish leaves) is common on high-pH (alkaline), sandy soils, especially during cool, wet weather in late May and June. Suggested treatment is to spray either manganese sulfate or an organic manganese formulation onto the leaves soon after the symptoms first appear. Broadcast application on the soil is ineffective because the manganese becomes unavailable in soils with a high pH.

Foliar application of MnEDTA at rates as low as 0.15 pound Mn per acre in mid-June to beans planted in early May provided a significant yield increase (Table 11.31). Delaying application until early July provided a slightly higher yield than did the mid-June application. In some cases, multiple applications may be necessary to optimize yield.

Table 11.32. Soil Situations and Crops Susceptible to Micronutrient Deficiency

Micronutrient	Sensitive crop	Susceptible soil situations	Conditions favoring deficiency
Zinc (Zn)	Young corn	1. Low in organic matter, either inherently or because of erosion or land shaping 2. High pH (>7.3) 3. Very high phosphorus 4. Restricted root zone 5. Coarse-textured (sandy) soils 6. Organic soils	Cool, wet
Iron (Fe)	Soybeans, grain sorghum	High pH	Cool, wet
Manganese (Mn)	Soybeans, oats	1. High pH 2. Restricted root zone 3. Organic soils	Cool, wet
Boron (B)	Alfalfa	1. Low organic matter 2. High pH 3. Strongly weathered soils in south-central Illinois 4. Coarse-textured (sandy) soils	Drought
Copper (Cu)	Corn, wheat	1. Infertile sand 2. Organic soils	Unknown
Molybdenum (Mo)	Soybeans	Acidic, strongly weathered soils in south-central Illinois	Unknown
Chlorine (Cl)	Unknown	Coarse-textured soils	Excessive leaching by low-Cl water

Wayne and Hark soybean varieties or lines developed from them often show iron deficiency on soils with a very high pH (usually 7.4 to 8.0). The symptoms are similar to those shown with manganese deficiency. Most of the observed deficiencies have been on Harpster, a "shelly" soil that occurs in low spots in some fields in central and northern Illinois.

Soybeans often outgrow the stunted, yellow appearance of iron shortage. As a result, it has been difficult to measure yield losses or decide whether or how to treat affected areas. Sampling by U.S. Department of Agriculture scientists indicated yield reductions of 30 to 50 percent in the center of severely affected spots. The yield loss may have been caused by other soil factors associated with a very high pH and poor drainage rather than by the iron deficiency itself.

Research in Minnesota has shown that time of iron application is critical to attaining a response. Researchers recommend that 0.15 pound of iron as iron chelate be applied per acre to leaves within 3 to 7 days after chlorosis symptoms develop (usually in the second-trifoliate stage of growth). Waiting for soybeans to grow to the fourth- or fifth-trifoliate stage before applying iron resulted in no yield increase. Because iron applied to the soil surface between rows does not help, applications directed over the soybean plants were preferred.

A significant yield response to zinc applications was observed at 3 of 85 sites evaluated in Illinois (Table 11.29). The use of zinc at the responding sites produced a corn yield that averaged 14.1 bushels per acre more than the check plots. Two sites were Fayette silt loams in Whiteside County, and one was a Green river sand in Lee County.

At two of the three responding sites, tests showed that the soil was low or marginal in available zinc. The soil of the third had a very high zinc level but was deficient in available zinc, probably because of the excessively high phosphorus level also found.

The zinc soil-test procedures accurately predicted results for two-thirds of the responding sites. The same tests, however, incorrectly predicted that 19 other sites would also respond. These results suggest that the soil test for available zinc can indicate where zinc deficiencies are found but does not indicate reliably whether the addition of zinc will increase yields.

To identify areas before micronutrient deficiencies become important, continually observe the most sensitive crops in soil situations in which the elements are likely to be deficient (Table 11.32).

In general, deficiencies of most micronutrients are accentuated by one of five situations: (1) strongly weathered soils; (2) coarse-textured soils; (3) high-pH soils; (4) organic soils; and (5) soils that are inherently low in organic matter or are low in organic matter because erosion or land-shaping processes have removed the topsoil.

The use of micronutrient fertilizers should be limited to areas of known deficiency, and only the deficient nutrient should be applied. An exception to this guideline would be situations in which farmers already in the highest yield bracket try micronutrients experimentally in fields that are yielding less than would be expected under good management, which includes an adequate nitrogen, phosphorus, and potassium fertility program and a favorable pH.

Method of Fertilizer Application

With the advent of new equipment, producers have a number of options for placement of fertilizer. These options range from traditional broadcast application to injection of the materials at varying depths in the soil. Selecting the proper application technique for a particular field depends at least in part upon the inherent fertility level, the crop to be grown, the land tenure, and the tillage system.

On fields where the fertility level is at or above the desired goal, there is little research evidence to show any significant difference in yield that is associated with method of application. In contrast, on low-testing soils and in soils that "fix" phosphorus, placement of the fertilizer within a concentrated band has been shown to result in higher yields, particularly at low rates of application. On higher-testing soils, plant recovery of applied fertilizer in the year of application is usually greater from a band than a broadcast application, though yield differences are unlikely.

Broadcast fertilization. On highly fertile soils, both maintenance and buildup phosphorus and potassium are efficiently utilized when broadcast and then plowed or disked in. This system, particularly when the tillage system includes a moldboard plow every few years, distributes nutrients uniformly throughout the entire plow depth. As a result, roots growing within that zone have access to high levels of fertility. Because the nutrients are intimately mixed with a large volume of soil, opportunity exists for increased nutrient fixation on soils having a high fixation ability. Fortunately, most Illinois soils do not have high fixation rates for phosphorus or potassium.

Row fertilization. On soils of low fertility, placement of fertilizer in a concentrated band below and to the side of the seed has been shown to be an efficient method of application, especially in situations for which the rate of application is markedly less than that needed

to build the soil to the desired level. Producers who are not assured of having long-term tenure on the land may wish to consider this option. The major disadvantages of this technique are (1) the additional time and labor required at planting time; (2) limited contact between roots and fertilizer; and (3) inadequate rate of application to increase soil levels for future crops.

For information on the use of starter fertilizer for no-till, see the description of fertilizer management related to tillage systems.

Strip application. With this technique, phosphorus, potassium, or both are applied in narrow bands on approximately 30-inch centers on the soil surface, in the same direction as the primary tillage. The theory behind this technique is that, after moldboard plowing, the fertilizer will be distributed in a narrow vertical band throughout the plow zone. This system reduces the amount of soil-to-fertilizer contact as compared with a broadcast application, and thus it reduces the potential for nutrient fixation. Because the fertilizer is distributed through a larger soil volume than with a band application, the opportunity for root-fertilizer contact is greater.

Deep fertilizer placement. Several terms have been used to define this technique, including root-zone banding, dual placement, knife injection, and deep placement. With this system a mixture of nitrogen-phosphorus or nitrogen-phosphorus-potassium is injected at a depth from 4 to 8 inches. The knife spacings may vary by crop to be grown, but generally they are 15 to 18 inches apart for close-grown crops such as wheat and 30 inches for row crops. This technique provided a significantly higher wheat yield as compared with a broadcast application of the same rate of nutrients in some, but not all, experiments conducted in Kansas. Wisconsin research showed the effect of this technique to be equivalent to a band application for corn on a soil testing high in phosphorus but inferior to a band application for corn on a soil testing low in phosphorus. If this system is used on low-testing soils, it is advisable to apply a portion of the phosphorus fertilizer in a band with the planter.

Dribble fertilizer. This technique applies urea–ammonium nitrate solutions in concentrated bands on 30-inch spacings on the soil surface. Results from several states have shown that this system reduces the potential for nitrogen loss of these materials, as compared with an unincorporated broadcast application. However, it has not been shown to be superior to an injected or an incorporated application of urea–ammonium nitrate solution.

"Pop-up" fertilization. The term "pop-up" is a misnomer. The corn does not emerge sooner with this kind of application, and it may come up 1 or 2 days later. The corn may, however, grow more rapidly during the first 1 to 2 weeks after emergence. Pop-up fertilizer will make corn look very good early in the season and may aid in early cultivation for weed control. But no substantial difference in yield is likely in most years due to a pop-up application as compared to fertilizer that is placed in a band to the side and below the seed. Seldom will there be a difference of more than a few days in the time the root system intercepts fertilizer placed with the seed as compared to that placed below and to the side of the seed.

Under normal moisture conditions, the maximum safe amount of N plus K_2O for pop-up placement is about 10 or 12 pounds per acre in 40-inch rows and correspondingly more in 30- and 20-inch rows. In excessively dry springs, even these low rates may result in damage to seedlings, reduction in germination, or both. Pop-up fertilizer is unsafe for soybeans. In research conducted at Dixon Springs, a stand was reduced to one-half by applying 50 pounds of 7-28-14 and reduced to one-fifth with 100 pounds of 7-28-14.

Site-specific application. Equipment has recently been developed that uses computer technology to alter the rate of fertilizer application as the truck passes across the field. This approach offers the potential to improve yield while minimizing the possibility of overfertilization. Yield improvement results from applying the correct rate (not a rate based on average soil test) to the low-testing portions of the field. Overfertilization is reduced by applying the correct rate (in many cases zero) to high-testing areas of the field. The combination of improved yield and reduced output results in improved profit.

Foliar fertilization. Researchers have known for many years that plant leaves absorb and utilize nutrients sprayed on them. Foliar fertilization has been used successfully for certain crops and nutrients. This method of application has had the greatest use with nutrients required in only small amounts by plants. Nutrients required in large amounts, such as nitrogen, phosphorus, and potassium, have usually been applied to the soil rather than the foliage.

The possible benefit of foliar-applied nitrogen fertilizer was researched at the University of Illinois in the 1950s. Foliar-applied nitrogen increased corn and wheat yield, provided that the soil was deficient in nitrogen. Where adequate nitrogen was applied to the soil, additional yield increases were not obtained from foliar fertilization.

Research in Illinois on foliar application of nitrogen to soybeans attempted to supply additional nitrogen to soybeans without decreasing nitrogen that was

Table 11.33. Yields of Corsoy and Amsoy Soybeans After Fertilizer Treatments Were Sprayed on the Foliage Four Times at Urbana

Treatment per spraying (lb/A)				Yield (bu/A)	
N	P_2O_5	K_2O	S	Corsoy	Amsoy
0	0	0	0	61	56
20	0	0	0	54	53
0	5	8	1	58	56
10	5	8	1	56	58
20	5	8	1	55	52
30	7.5	12	1.5	52	46

symbiotically fixed. It was thought that if nitrogen application were delayed until after nodules were well established, perhaps symbiotic fixation would remain active. Neither single nor multiple applications of nitrogen solution to foliage increased soybean yields. Damage to vegetation occurred in some cases because of leaf "burn" caused by the nitrogen fertilizer.

Although considerable research in foliar fertilization had been conducted in Illinois already, new studies were done in 1976 and 1977. This research was prompted by a report from a neighboring state that soybean yields had recently been increased by as much as 20 bushels per acre in some trials. Research in that state differed from earlier work on soybeans in that, in addition to nitrogen, the foliar fertilizer increased yield only if phosphorus, potassium, and sulfur were also included. Researchers there thought that soybean leaves become deficient in nutrients as nutrients are translocated from vegetative parts to the grain during grain development. They reasoned that foliar fertilization, which would prevent leaf deficiencies, should result in increased photosynthesis that would be expressed in higher grain yields.

Foliar fertilization research was conducted at several locations in Illinois during 1976 and 1977, ranging from Dixon Springs in the south to DeKalb in north. None of the experiments gave economical yield increases. In some cases there were yield reductions, attributed to leaf damage caused by the fertilizer. Table 11.33 contains data from a study at Urbana in which soybeans were sprayed four times with various fertilizer solutions. Yields were not increased by foliar fertilization.

Nontraditional Products

In this day of better-informed farmers, it seems hard to believe that letters, calls, and promotional leaflets about nontraditional products are increasing. The claim made is usually that "Product X" either replaces fertilizers and costs less, makes nutrients in the soil more available, supplies micronutrients, or is a natural product without strong acids that kill soil bacteria and earthworms.

The strongest position that agronomists can take is to challenge these peddlers to produce unbiased research results in support of their claims. Testimonials by farmers are no substitute for research.

Extension specialists at the University of Illinois are ready to give unbiased advice when asked about purchasing new products or accepting a sales agency for them.

In addition, each Extension office has the publication *Compendium of Research Reports on the Use of Nontraditional Materials for Crop Production*, which contains data on a number of nontraditional products that have been tested in the Midwest. Check with the nearest Extension office for this information.

Authors

Robert G. Hoeft
Department of Crop Sciences

Theodore R. Peck
Department of Natural Resources and Environmental Sciences

Chapter 12.
Soil Management and Tillage Systems

Soils are a natural resource. In Illinois, the greatest concern for soil degradation is erosion caused by water. The potential for erosion of a specific soil type, slope, and slope length largely depends on the crops grown and the number and types of tillage operations used to produce them. Several techniques are available to reduce soil erosion, including residue management, crop rotation, contouring, grass waterways, terraces, and conservation structures. The techniques adopted must ensure the long-term productivity of the land, be environmentally sound, and, of course, be profitable. Residue management, consisting of mulch tillage and no-tillage farming systems, is recognized as a cost-effective means of significantly reducing soil erosion and maintaining productivity.

Conservation Compliance

A dramatic step taken to encourage the adoption of techniques to control soil erosion was the passage of the 1985 Food Security Act. Conservation requirements were also included in the 1990 and 1996 versions of the Farm Bill. Conservation compliance is a major provision of the federal legislation. The goal is to reduce soil erosion to levels that will maintain the long-term productivity of the land. For a farmer to remain eligible for many USDA programs, conservation compliance provisions of the laws require the farmer to follow an approved conservation system on highly erodible fields. Conservation systems must meet specifications or guidelines of the *Natural Resources Conservation Service Field Office Technical Guide* and must be approved by the local conservation district. Most conservation compliance systems include use of mulch tillage or no-tillage. Even though conservation compliance pertains only to highly erodible fields, many farmers are adopting conservation tillage systems not only to reduce soil erosion but because they reduce labor and equipment costs and can be more profitable.

Federal conservation provisions focus on reducing soil erosion. Growing concerns about water quality are likely to be an issue in hammering out future state and federal legislation. Many conservation practices help preserve water quality. Conservation tillage, terraces, strip cropping, contouring, grass waterways, and filter strips all reduce water runoff and soil erosion and thus help preserve water quality.

As indicated earlier, the tillage system selected to produce a crop has a significant effect on soil erosion, water quality, and profitability. Profitability, of course, is determined from crop yield (net income) and costs. Selecting a tillage system is thus an important management decision. Before the factors are discussed in detail, several tillage systems will be defined.

Conservation Tillage Systems

The objective of conservation tillage is to provide a means of profitable crop production while minimizing soil erosion due to wind and water. The emphasis is on soil conservation, but the conservation of soil moisture, energy, labor, and even equipment provides additional benefits. To be considered conservation tillage, the system must provide conditions that resist erosion by wind, rain, and flowing water. Such resistance is achieved either by protecting the soil surface with crop residues or growing plants or by maintaining sufficient surface roughness or soil permeability to control soil erosion.

Conservation tillage is often defined as any crop production system that provides either (1) a residue cover of at least 30 percent after planting to reduce soil erosion due to water or (2) at least 1,000 pounds per acre of flat, small-grain residues (or the equivalent) on the soil surface during the critical erosion period to reduce soil erosion due to wind.

The term conservation tillage represents a broad spectrum of tillage systems. However, maintaining an effective amount of plant residue on the soil surface is

the crucial issue, which is why the Natural Resources Conservation Service (NRCS) has replaced conservation tillage with the term crop residue management. This term refers to a philosophy of year-round management of residue to maintain the level of cover needed for adequate control of erosion. Adequate erosion control often requires more than 30 percent residue cover after planting. Other conservation practices or structures may also be required.

Conservation tillage or crop residue management includes a broad spectrum of tillage systems, some of which are described here.

No-Till

With no-till, the soil is left undisturbed from harvest to seeding and from seeding to harvest. The only "tillage" is the soil disturbance in a narrow band created by a row cleaner, coulter, seed furrow opener, or other device attached to the planter or drill. Many no-till planters are now equipped with row cleaners to clear row areas of residue. No-till planters and drills must be able to cut residue and penetrate undisturbed soil. No-till planting of corn and no-till drilling or no-till planting in narrow rows of soybeans have increased in Illinois.

Strictly speaking, a no-till system does not allow operations that disturb the soil other than the planting or drilling operation. However, the basic no-till system is sometimes modified by the use of a strip tillage operation which often includes knife fertilizer application.

Ridge-Till

With ridge-till, also known as ridge-plant or till-plant, the soil is left undisturbed from harvest to planting except for fertilizer application. Crops are planted and grown on ridges formed in the previous growing season. Typically, ridges are built and reformed annually during row cultivation. A planter equipped with sweeps, disk row cleaners, coulters, or horizontal disks is used in most ridge-till systems. These row-cleaning attachments remove 1 to 2 inches of soil, surface residue, and weed seeds from the row area. Ideally, this process leaves a residue-free strip of moist soil on top of the ridges into which the seed is planted. Special heavy-duty row cultivators are used to reform the ridges. Corn and grain sorghum stalks are sometimes shredded between harvest and planting.

Mulch-Till

Mulch-till includes any conservation tillage system other than no-till and ridge-till. Deep tillage might be performed with a subsoiler or chisel plow; tillage before planting might include one or more passes with a disk harrow, field cultivator, or combination tool. Herbicides or crop cultivation, or both together, control weeds. The tillage tools must be equipped, adjusted, and operated to ensure that adequate residue cover remains for erosion control, and the number of operations must also be limited. At least 30 percent of the soil surface must be covered with plant residue after planting.

Other Tillage Systems

Conventional Tillage

Conventional tillage is the sequence of tillage operations traditionally or most commonly used in a given geographic area to produce a given crop. The operations used vary considerably for different crops and different regions. In the past, conventional tillage in Illinois included moldboard plowing, usually in the fall. Spring operations included one or more disk harrowings or field cultivations before planting or drilling. The soil surface with conventional tillage was essentially free of plant residue and provided a high potential for soil erosion. The term *clean tillage* is also used for any system that provides a residue-free soil surface. A soil surface essentially free of residues can also be achieved with other implements, especially following a crop such as soybeans that produces fragile, easy-to-cover residue.

Systems Named by Major Implement

Several tillage systems are named according to the major implement used, including moldboard plow, chisel plow, subsoiler, disk, and field cultivator. These systems may be "mulch tillage" systems if at least 30 percent of the soil surface is covered with residue after planting. With these systems, herbicides may be incorporated into the soil before planting using a disk harrow, field cultivator, or combination tool. No-till attachments are not needed on the planter or drill. Crops planted in rows can be row cultivated.

Minimum Tillage

The term *minimum tillage* is not very meaningful, but it is still used by some. Minimum tillage means the minimum soil manipulation necessary for crop production or meeting tillage requirements under existing conditions. When most people use the term *minimum tillage*, they mean reduced tillage (defined in the next section).

Reduced Tillage

Reduced tillage refers to any system that is less intensive and aggressive than conventional tillage. Compared to conventional tillage, the number of operations is decreased, or a tillage implement that requires less energy per unit area is used to replace an implement typically used in the conventional tillage system. The term is sometimes used to mean the same as conservation tillage. However, to be considered a conservation tillage system, 30 percent of the soil surface must be covered with residue after planting. Because it is not specific, the term *reduced tillage* is not very useful.

Rotary-Till

For the rotary-till system, a powered rotary tiller is used in the fall or spring before planting. The planter may be attached directly to the rotary tiller. This system is not widely used in Illinois.

Effects of Tillage on Soil Erosion

A primary advantage of conservation tillage systems, particularly no-till, is less soil erosion due to water on sloping soils. Although wind erosion in Illinois is not as great a problem as water erosion, conservation tillage systems also essentially eliminate wind erosion. A bare, smooth soil surface is extremely susceptible to erosion. Many Illinois soils have subsurface layers that are not favorable for root growth and development. Soil erosion slowly but continually removes the topsoil that is most favorable for root development, resulting in gradually decreasing soil productivity and value. Even on soils without root-restricting subsoils, erosion removes nutrients that must be replaced with additional fertilizers to maintain yields.

An additional problem related to soil erosion is sedimentation and the nutrients, pesticides, and other materials carried by the sediment and water. Sediment and other materials from eroding fields increase water pollution, reduce storage capacities of lakes and reservoirs, and decrease the effectiveness of surface drainage systems.

Surface residues effectively reduce soil erosion. A residue cover of 20 to 30 percent after planting reduces soil erosion by approximately 50 percent compared to a bare field. A residue cover of 70 percent after planting reduces soil erosion more than 90 percent compared to a bare field. On long, steep slopes, conservation tillage will not adequately control soil erosion. Other practices are thus required, such as contouring, grass waterways, terraces, or structures. For technical assistance in developing erosion control systems, consult your district conservationist or the NRCS.

Residue Cover

The percentage of the soil surface covered with residue after planting is affected by the previous crop grown and the tillage system used. In general, the higher the crop yield, the greater the residue produced. More important, however, is the type of residue a crop produces. Types of residue produced by various crops have been classified as nonfragile or fragile (Table 12.01). The classification is subjective and based on the ease with which the residues are decomposed by the elements or buried by tillage operations. Plant characteristics such as composition and sizes of leaves and stems, density of the residues, and relative quantities produced were considered. The residues of a crop such as soybeans are considered fragile because essentially all of the residues are damaged in passing through the combine, the stems and stubble are small in diameter, and the leaves are small and fall from the plants well before harvest. In contrast, residues from corn are classified as nonfragile.

Table 12.01. Types of Residue Produced by Various Crops

Nonfragile	Fragile
Alfalfa or legume hay	Canola/rapeseed
Barley*	Dry beans
Buckwheat	Dry peas
Corn	Fall-seeded cover crops
Flaxseed	Flower seed
Forage seed	Green peas
Forage silage	Potatoes
Grass hay	Soybeans
Millet	Vegetables
Oats*	
Pasture	
Popcorn	
Rye	
Sorghum	
Triticale*	
Wheat*	

NOTE: From *Estimates of Residue Cover Remaining After Single Operation of Selected Tillage Machines*, developed jointly by the Soil Conservation Service, USDA, and Equipment Manufacturers Institute. First edition, February 1992.
*If a combine is equipped with a straw chopper or the straw is otherwise cut into small pieces, small-grain residue should be considered fragile.

Cornstalks, leaves, and cobs are individually large in size and quite durable, and the total mass of residue produced is greater.

The line-transect method is often used to measure residue cover. A light rope or tape with 100 equally spaced knots or marks is stretched diagonally across the crop rows. Residue cover is measured by counting each knot or mark that is directly over a piece of residue. The percent residue cover is equal to the number of knots counted.

Often there is a desire to predict the amount of residue that will remain on the soil surface using a particular tillage system. The prediction requires knowing the amount of residue cover remaining after each field operation included in the tillage system. Typical percentages of the residue cover remaining after various field operations are given in Table 12.02. The percentages can be used to estimate the residue cover after each field operation in a tillage system.

A corn crop of 150 bushels per acre will usually provide a residue cover of 95 percent after harvest. Grain sorghum, most small grains, and lower yielding corn will generally provide a cover of 80 to 90 percent. Following soybean harvest, 70 to 80 percent cover typically remains. In all cases, the residue must be uniformly spread behind the combine. For a tillage system, a rough approximation of the residue cover remaining after planting can be obtained by multiplying the initial percent residue cover by the values in Table 12.02 of percent cover remaining after each operation. To leave 30 percent or more residue cover following corn, only one or two tillage operations can be performed. To leave 30 percent cover following soybeans essentially requires that the no-tillage system be used.

Crop Production with Conservation Tillage

Crop response to various tillage systems is variable in both farmers' fields and experimental plots. The variability is often difficult to explain because so many aspects of crop production are influenced by tillage. Crop germination, emergence, and growth are largely regulated by soil temperature, aeration, and moisture content; nutrient availability to roots; and mechanical impedance to root growth.

Soil Temperature

Crop residue on the soil surface insulates the soil from the sun's energy. In most of Illinois, higher soil temperatures than normal are desirable for plant growth in the spring. Later in the season, temperatures cooler than normal are often desirable.

Table 12.02. Residue Cover Remaining on the Soil Surface After Weathering or Specific Field Operation

	Percent of residue remaining	
	Nonfragile	Fragile
Climatic effects		
Overwinter weathering*		
Following summer harvest	70–90	65–85
Following fall harvest	80–95	70–80
Field operations		
Moldboard plow	0–10	0–5
V ripper/subsoiler	70–90	60–80
Disk-subsoiler	30–50	10–20
Chisel plow with		
Straight spike points	60–80	40–60
Twisted points or shovels	50–70	30–40
Coulter-chisel plow with		
Straight spike points	50–70	30–40
Twisted points or shovels	40–60	20–30
Offset disk harrow— heavy plowing > 10" spacing	25–50	10–25
Tandem disk harrow		
Primary cutting > 9" spacing	30–60	20–40
Finishing 7" to 9" spacing	40–70	25–40
Light disking after harvest	70–80	40–50
Field cultivator		
As primary tillage operation		
Sweeps 12" to 20"	60–80	55–75
Sweeps or shovels 6" to 12"	35–75	50–70
As secondary tillage operation		
Sweeps 12" to 20"	80–90	60–75
Sweeps or shovels 6" to 12"	70–80	50–60
Combination finishing tool with		
Disks, shanks, and leveling attachments	50–70	30–50
Spring teeth and rolling baskets	70–90	50–70
Anhydrous ammonia applicator	75–85	45–70
Drill		
Conventional	80–100	60–80
No-till	55–80	40–80

Table 12.02. Residue Cover Remaining on the Soil Surface After Weathering or Specific Field Operation (cont.)

	Percent of residue remaining	
	Nonfragile	Fragile
Conventional planter	85–95	75–85
No-till planter with		
Ripple coulters	75–90	70–85
Fluted coulters	65–85	55–80
Ridge-till planter	40–60	20–40

NOTE: From *Estimates of Residue Cover Remaining After Single Operation of Selected Tillage Machines*, developed jointly by the Soil Conservation Service, USDA, and Equipment Manufacturers Institute. First edition, February 1992.
*With long periods of snow cover and frozen conditions, weathering may reduce residue levels only slightly, while in warmer climates, weathering losses may reduce residue levels significantly.

Minimum daily temperatures of the soil surface usually occur between 6 a.m. and 8 a.m., and in spring they are often the same or slightly higher with residue cover than without. Maximum daily temperatures of the soil surface occur between 3 p.m. and 5 p.m., and with clean tillage they are 3° to 6°F warmer than those with residue cover. During the summer, a complete crop canopy restricts the influence of crop residue on soil temperature, and soil surface temperatures are about the same with and without surface residue.

During May and early June, the reduced soil temperatures caused by a surface mulch influence early plant growth. In northern regions of the state, average daily soil temperatures are often close to the temperature at which corn grows, and the reduced temperatures caused by surface residues result in slow plant growth. In southern regions of the state, average daily temperatures are usually well above the temperature at which corn grows, and the reduced temperatures caused by surface residues have little, if any, effect on early corn growth.

The amount of residue influences soil temperature. Residues from corn, wheat, and grass sod maintain cooler soil than residue from soybeans and other crops that produce less residue or residue that decomposes rapidly.

Whether the lower soil temperature and subsequent slower early growth result in lower yields depends largely on weather conditions during the summer. Research shows that lower yields with reduced tillage systems occur most often on poorly drained soils and on all soils in northern Illinois in years not affected by drought. In these situations, soil temperature, corn growth, and yield potential often improve when residues are removed from the row area. Several planter attachments are available for removing residue from the row area. However, on well-drained soils in southern Illinois, reduced soil temperature caused by in-row residues may increase crop growth and yield.

Allelopathy

Allelopathy refers to toxic effects on a crop due to decaying residue from the same crop or closely related species. Greenhouse studies have shown that toxins and bacteria from decaying residue affect growth of new plants. In the field, it is difficult to separate allelopathic effects from soil temperature effects. The toxic effect is most likely to occur when corn follows corn, rye, or wheat or when wheat follows rye or wheat, and when residue is on or near the soil surface near the growing crop. Planter attachments which remove residue from the row area may reduce the toxic effect.

Moisture

When 30 percent or more of the soil surface is covered with residues, generally evaporation is reduced and water infiltration increases, leading to more water stored in sloping soils. More stored water may be advantageous in dry summer periods but may be disadvantageous at planting time and during early growth—especially on soils with poor internal drainage.

In most years in Illinois, extra water is needed after the crop canopy closes. In Kentucky, evaporation and transpiration were estimated for no-till and moldboard plowed plots. Average annual evaporation was reduced by 5.9 inches with no-till. Thus, it was concluded that more water is available for transpiration with no-till, often resulting in higher corn yields.

Soil moisture saved through reduced tillage systems may be important in years with below-normal rainfall. In the northern half of Illinois excessive soil moisture in the spring months often reduces crop growth because it slows soil warming and may delay planting. However, on soils where drought stress often occurs during summer months, additional stored moisture leads to higher yields.

Organic Matter and Aggregation

Soil organic matter tends to stabilize at a certain level for a specific tillage system. Moldboard plowing buries essentially all of the residue and increases oxidation of organic matter. With conservation tillage systems, especially no-till and ridge-till, residue is left on the soil surface where decomposition is slow, which then causes organic matter in the upper few inches to increase after several years.

Both the amount and distribution of organic matter change with the tillage system (Table 12.03). Compared to moldboard plowing, organic matter with no-till gradually increases near the soil surface and is maintained or increased slightly below a depth of 4 inches. It is assumed that with mulch-tillage systems, organic matter would approach a level between moldboard plow and no-till systems.

Soil Density

An increase in soil density is often referred to as compaction. Excessive soil compaction restricts plant root growth, impedes drainage, reduces soil aeration, increases injury potential of some herbicides, and reduces uptake of potassium and nitrogen. Untilled soil usually has a greater density than tilled soil. However, after soil is loosened by tillage, density increases due to wetting and drying, wheel traffic, and secondary tillage operations. By harvest time soil density is often about equal to that of untilled soil. Wheel traffic of heavy equipment such as tractors, combines, and grain carts may cause plant rooting to be limited or redirected with any tillage system.

In an experiment at the University of Illinois, corn and soybeans have been grown with and without wheel traffic compaction on tilled soil before planting (Table 12.04). Heavy wheel traffic on the entire soil surface significantly decreased corn yields when rainfall was adequate or excessive. In years with excessive rainfall, ponding of water occurred on plots with the entire surface compacted, and corn yields were reduced significantly. On other plots, wheel traffic was applied to every other row of the plot area before planting—which may be more typical of field conditions. On these plots, yields were not significantly affected compared to yields from no-extra-compaction plots.

Table 12.03. Amount and Distribution of Soil Organic Matter with Plow and No-Till Systems[a]

	Sandy loam		Silty clay loam	
Tillage system	Depth (in.)	OM (%)	Depth (in.)	OM (%)
Plow	0–4	1.5	0–3	4.1
	4–8	1.5	3–6	4.1
	8–12	0.8	6–9	3.7
No-till	0–4	1.9	0–3	4.8
	4–8	1.7	3–6	4.2
	8–12	0.9	6–9	3.8

[a]Indiana, after growing continuous corn for 7 years.

Stand Establishment

Uniform planting depth, good contact between the seed and moist soil, and enough loose soil to cover the seed are necessary to consistently produce uniform stands. Planting shallower than normal in the cool, moist soil common to many conservation tillage seedbeds may partially offset the disadvantage of lower temperatures. However, if dry, windy weather follows planting, germination may be poor, and shallow-planted seedlings may be stressed for moisture. A normal planting depth is thus suggested for all tillage systems.

For most conservation tillage systems, planters and drills are equipped with coulters in front of each seed furrow opener to cut the surface residues and penetrate the soil. Row cleaners can also be mounted in front of each seed opener. Generally, coulters should be operated at seeding depth. Row cleaners should be set to move the residue from the row area and to move as little soil as possible. Extra weight is often needed on planters and drills for no-till so that the soil-engaging components function properly and sufficient weight is ensured on the drive wheels. Heavy-duty, down-pressure springs may also be necessary on each planter unit to penetrate firm, undisturbed soil.

Table 12.04. Effects of Wheel Traffic Compaction on Soybean and Corn Yields at Urbana

	11-year average yields (bu/A)	
Compaction treatment	Soybeans	Corn
No extra compaction	40.3	163
Half-surface compaction	40.0	160
Entire surface compacted	38.8	150[a]

[a]Soil compaction caused water to pond after heavy rain in some years.

Fertilizer Placement

See the "Fertilizer Management Related to Tillage Systems" section in Chapter 11 for discussion of this topic.

Weed Control

Controlling weeds is essential for profitable production with any tillage system. With less tillage, weed control becomes more dependent on herbicides. However, effective herbicides are available for controlling most all weeds in conservation tillage systems. Herbicide selection and application rate, accuracy, and timing become more important. Application accuracy is especially important with drilled soybeans because row cultivation is impractical. (For specific herbicide recommendations, see Chapter 15.)

Perennial weeds, such as milkweed and hemp dogbane, may be a problem with conservation tillage systems. Excellent postemergence controls are now available for weeds such as johnsongrass, shattercane, and yellow nutsedge that formerly required incorporated treatments. Volunteer corn is often a potential problem with tillage systems that leave corn lost at harvest on the soil surface or at a shallow depth. However, excellent herbicides are now available for control of volunteer corn in soybeans. Unless control programs are monitored closely, surface-germinating weeds, such as fall panicum and crabgrass, may also increase with reduced-tillage systems. Some broadleaf weeds such as velvetleaf are often less of a problem with no-till.

Surface-applied and incorporated herbicides may not give optimum performance under tillage systems that leave large amounts of crop residue and clods on the soil surface. These problems interfere with herbicide distribution and thorough herbicide incorporation.

Herbicide incorporation is impossible in no-till systems. Residual or postemergence herbicides are effective, and mechanical cultivation is usually not done.

Heavy-duty cultivators are available to cultivate with high amounts of surface residues and hard soil. High amounts of crop residues interfere with some rotary hoes and cultivators with multiple sweeps per row. Cultivators equipped with a single coulter and sweep plus two weeding disks per row are effective across a wide range of soil and crop residue conditions.

With the ridge-tillage system, special cultivation equipment is necessary to form a sufficiently high ridge and to operate through the inter-row residue. Weed control is also accomplished as ridges are rebuilt.

No-Till Weed Control

In conventional and most conservation-tillage systems, existing weeds are destroyed by tillage before planting. No-till systems may require a knockdown herbicide like paraquat or Roundup to control existing vegetation. However, some herbicides, such as Extrazine, may provide both "burndown" and residual control. The vegetation may be a grass or legume sod or early germinating annual and perennial weeds. Alfalfa and certain perennial broadleaf weeds are not well controlled by paraquat or Roundup. For corn it may be necessary to treat these weeds with Banvel or 2,4-D. A combination of 2,4-D and Banvel is often best to broaden the spectrum of control. Horseweed and prickly lettuce are often associated with no-till. A combination of Roundup plus 2,4-D is often appropriate as a burndown for such weeds.

Insect Management

Although insect problems and management practices may be affected by reduced tillage, concern about insect problems should not prevent a farmer from adopting conservation tillage practices. With few exceptions, effective insect-management guidelines and tactics are available, regardless of the tillage system used. Extension entomologists throughout the north central region of the United States seldom alter insect-management recommendations for different tillage systems.

Insect development rates are closely related to temperature. Insects that spend part of their life cycles in the soil may develop more slowly in conservation tillage systems. For instance, initial emergence of corn rootworm adults is delayed in no-till corn fields. The type of tillage system may also influence insect survival during the winter. Research has shown that survival of corn rootworm eggs during the winter is greater in no-till systems than in more conventional systems, especially if snow cover is deficient and if temperatures remain very cold for an extended period.

Conservation tillage systems may affect other components that influence insect populations, such as weed densities and populations of beneficial insects. Poor weed management in some tillage systems is responsible for increasing the densities of cutworms, for example. On the other hand, some weeds attract predators and parasitoids that may suppress some insect pest populations.

The effects of tillage on insects are most prominent in corn. The insects most directly affected are those that overwinter in the soil and become active during the early stages of crop growth. Increases in grassy weed populations, reduced disturbance of soil, and delayed germination caused by cooler soil temperatures may favor the buildup of white grubs and

wireworms. Seedcorn maggot flies prefer to lay eggs where crop residue has been partially incorporated into the soil. No-till corn stubble may be less attractive to egg-laying flies, but cooler, wetter soils shaded by crop residues may slow germination and increase the period of vulnerability to seedcorn maggot injury. On the other hand, corn rootworms are little affected by conservation tillage (Table 12.05).

Although soil-dwelling insects are usually affected more than the foliage-feeding insects, some species respond to certain weeds. Black cutworm moths prefer to lay eggs in weedy fields and in fields with unincorporated crop residues. Ryegrass and other grass cover crops, hay crops, and grassy weeds are especially attractive to egg-laying armyworm moths. In no-till fields, serious damage by stalk borers is most likely where grasses were present to attract egg-laying moths during August and September of the previous year.

Conservation tillage favors greater survival of European corn borers in crop residue, but effects in specific fields are minor because moths disperse from emergence sites to lay eggs in suitable fields throughout the local area. Where reduced tillage leads to later planting or slower growth, corn may be less susceptible to attack by first-generation corn borers and more susceptible to second-generation damage.

Although the potential for insect problems is slightly greater with conservation tillage than it is in plowed fields, adequate management guidelines are generally available (Chapter 17).

Disease Control

The potential for plant disease is greater when mulch is present than when fields are clear of residue. With clean tillage, residue from the previous crop is buried or otherwise removed. Because buried residue is subject to rapid decomposition, overwintering of pathogens is lessened or reduced with clean tillage systems.

If volunteer corn in continuous corn is a hybrid that is susceptible to disease, early infection with diseases such as southern corn leaf blight or grey leaf spot, for instance, will increase.

Although the potential for plant disease is greater with conservation tillage systems than with clean tillage, disease-resistant hybrids and varieties can help reduce this problem. The erosion-control benefit of conservation tillage must be balanced against the increased potential for disease. Crop rotation or modification of the tillage practice may be justified if a disease cannot otherwise be controlled.

Table 12.05. Potential Effects of Conservation Tillage Systems on Pests in Corn

Insect	Potential effect*
Armyworm	0 to + + +
Black cutworm	+ to + + +
Corn earworm	0 to +
Corn leaf aphid	0
Corn rootworm	0
European corn borer	0 to +
Hop vine borer	0 to + + +
Seedcorn maggot	+
Slugs	+ + +
Stalk borer	0 to + + +
Stink bugs	+
White grubs	+
Wireworms	+

* Potential effects depend on cropping sequence, weather conditions, and presence or absence of weeds. 0 = no effect in pest population; + = some increase; + + + = substantial increase.

Crop Yields

Tillage research is conducted at the six University of Illinois Agricultural Research and Demonstration Centers (see map on inside front cover) to evaluate crop yield responses to different tillage systems under a wide variety of soil and climatic conditions. Crop yields vary, due more to weather conditions during the growing season than the tillage system used. Corn and soybean yields are generally higher when the crops are rotated compared to either crop grown continuously. It is important with any tillage system that plant stands be adequate, weeds be controlled, soil compaction not be excessive, and adequate nutrients be available.

Comparative yields due to tillage system vary with soil type (Table 12.06). In general, corn and soybean yields have been found to decrease slightly as tillage is reduced on poorly drained and somewhat poorly drained dark soils. An exception is the ridge-till system, which frequently produces higher corn yields on these soils. Flanagan silt loam and Drummer silty clay loam are two examples of poorly drained to somwhat poorly drained soils.

On well-drained to moderately well-drained, medium-textured, dark- and light-colored soils, expected yields with all tillage systems are quite similar for rotation corn and soybeans. With continuous corn, yields generally decrease as tillage is reduced.

Tama silt loam, which is dark, and Downs-Fayette silt loam, which is light-colored, are both well-drained to moderately well-drained and medium-textured.

On somewhat excessively drained sandy soils, conservation tillage systems that retain surface residues reduce wind erosion and conserve moisture, typically producing high yields.

Soils such as Cisne silt loams, which are very slowly permeable and poorly drained, have a clay pan that restricts root development with all tillage systems. On such soils, yields are frequently higher with less tillage.

Production Costs

For evaluating the profitability of various tillage–planting systems, the related costs are an important consideration. Various systems may affect the cost of machinery, labor, fertilizers, pesticides, and seed. Grain-handling and drying costs are affected if yields differ. Land cost is normally assumed not to vary with tillage system.

Machinery and Labor Costs

Machinery-related costs for Illinois farms typically overshadow all other cost categories except land. Machinery-related costs include the expenses for owning and operating machinery and for labor to operate it. Many factors and assumptions must be made to estimate these costs for a farm and for various tillage systems.

Machinery-related costs were estimated using a computerized farm machinery selection program that determines the optimum set of machinery for a farm. The optimum set of machinery is the one resulting in the minimum total cost for machinery and labor which will complete all field operations in a timely manner with assumed workday probabilities. The program assumes new machinery is purchased and used for up to 10 years. Machinery costs include depreciation, interest, insurance, housing, repairs, fuel, and lubrication. The program was used to determine the optimum machinery set for various tillage systems and farm sizes. For each machinery set, estimated machinery and labor costs were calculated. The field operations for the tillage systems are summarized in Table 12.07.

Total costs for machinery and labor per acre decrease as the amount of tillage is reduced and as farm size increases (Table 12.08). For reduced tillage, fewer implements and field operations are used, and the necessary power units are often smaller for a given

Table 12.06. Corn and Soybean Yields with Moldboard Plow, Chisel Plow, Disk, and No-Till Systems

	Soil type					
Tillage system	Thorp silt loam	Alford silt loam	Flanagan silt loam and Drummer clay loam	Cisne silt loam	Downs-Fayette silt loam	Tama silt loam
	average corn yields following soybeans (bu/A)					
Moldboard plow	. . .	146[b]	160[c]	. . .	172[e]	165[f]
Chisel plow	167[a]	145	145	138[d]	170	155
Disk	169	. . .	154	138	171	165
No-till	165	145	151	133	167	159
	average soybean yields following corn (bu/A)					
Moldboard plow	42	40	50	28	44	54
Chisel plow	. . .	40	49	29	47	55
Disk	43	. . .	48	. . .	46	53
No-till	40	45	48	32	45	53

[a]Urbana.
[b]Dixon Springs.
[c]DeKalb.
[d]Brownstown.
[e]Perry.
[f]Monmouth.
. . . System not included in experiment.

farm size. If a reduced tillage system is used on only part of the land farmed, implements and tractors will need to be available for other portions, so savings may be smaller than indicated in Table 12.08.

With reduced tillage systems, labor costs are less because some fall or spring tillage operations are less intensive or eliminated. The labor saved in this way has value only if it reduces the cost of hired labor or if the saved labor time is directed into other productive activities, such as raising livestock, working off-farm, or farming more land.

Using a drill or narrow-row planter for soybeans is an option for most tillage systems. However, owning a drill for soybeans and a planter for corn often increases the machinery inventory and costs for a corn-soybean farm. The effects on machinery cost for the farm depend on farm size and the cost of the drill. Some no-till drills are quite expensive. For systems that include row cultivation of planted soybeans, the cost increase of the drill may be offset by less use of the planter, row cultivator, and tractor. In comparing no-till planted soybeans (no row cultivation) with no-till drilled soybeans, the no-till drill increases estimated optimum machinery and labor costs from $38.60 to $45.60 per acre for a 1,000-acre corn-soybean farm (Table 12.08).

An extra cost for additional or more expensive pesticides may be associated with some conservation tillage systems. For example, a "burndown" herbicide may be needed with no-till and ridge-tillage systems. These increases are usually more than offset by reduced machinery and labor costs with conservation tillage. Ridge-till can be cost-effective, especially if only a band application of herbicide is used.

Costs for corn and soybean seeds are usually the same for all tillage systems. However, when soybeans are drilled or planted in narrow rows, the seeding rate is usually increased 10 to 20 percent compared to planting in rows 30 inches or wider.

Usually the amounts of fertilizers and lime are not varied with different tillage systems. However, the forms and application techniques may vary depending on the tillage system. Any differences in cost should be considered. A starter fertilizer for corn is often recommended with conservation tillage, especially with the no-till system. Planter attachments to apply starter fertilizer in a separate band are an expense that should be considered.

Table 12.07. Tillage Operations for Various Systems

	Tillage system							
After soybeans	Chisel		Field cultivate		Field cultivate		No-till	
After corn	Plow		Chisel		Disk		No-till	
Fall								
Harvest	S	C	S	C	S	C	S	C
Mb plow		*						
Chisel plow	*			*				
Apply NH_3[a]	*		*		*		*	
Spring								
Disk		*		*		*		
Field cultivate	*	*	*	*	*	*		*
Plant	C	S	C	S	C	S	C	S
Row cultivate	*	*	*	*	*	*		

S = soybeans, C = corn.
[a] Portions of anhydrous ammonia were applied in fall, in spring, or as sidedress.

Table 12.08. Estimated Machinery-Related Costs for Various Corn and Soybean Farm Sizes and Tillage Systems[a]

Farm size and tillage system[b]	Tractors (no.-Hp)	Combines (no.-Hp)	Costs ($/acre) Machinery	Labor[c]	Total
Corn and soybeans planted					
500 acres					
Mb plow/chisel	1-120	1-160	77.70	12.30	90.00
Chisel/disk	1-120	1-160	71.80	10.60	82.40
Disk/field cultivator	2-80	1-160	69.50	11.70	81.20
No-till/no-till	1-80	1-160	52.10	7.00	59.10
750 acres					
Mb plow	1-140, 1-80	1-160	64.00	11.90	75.90
Chisel	1-120, 1-80	1-160	59.60	10.75	70.35
Disk/field cultivator	2-80	1-160	52.30	11.70	64.00
No-till/no-till	1-80	1-160	39.20	7.00	45.20
1,000 acres					
Mb plow/chisel	1-160, 1-80	1-220	59.80	9.00	68.80
Chisel/disk	1-160, 1-80	1-220	53.30	8.10	61.40
Disk/field cultivator	1-160, 1-80	1-220	52.90	7.50	60.40
No-till/no-till	1-100	1-190	36.60	5.30	41.90
1,500 acres					
Mb plow/chisel	1-220, 1-100	1-220	55.40	7.22	62.62
Chisel/disk	1-200, 1-100	1-220	50.00	6.50	56.50
Disk/field cultivator	1-220, 1-100	1-220	48.50	6.20	54.70
No-till/no-till	1-100	1-220	33.10	4.40	37.50
2,000 acres					
Mb plow/chisel	2-180, 1-120	1-275	55.30	7.00	62.30
Chisel/disk	1-220, 1-120	1-275	46.90	5.50	52.40
Disk/field cultivator	1-220, 1-120	1-275	46.80	5.20	52.00
No-till/no-till	1-120	1-275	31.50	3.30	34.80
Corn planted and soybeans drilled					
500 acres					
Mb plow/chisel	1-100, 1-80	1-160	76.60	14.70	91.30
Chisel/disk	1-100, 1-80	1-160	72.50	12.70	85.20
Disk/field cultivator	2-80	1-160	65.40	12.80	78.20
No-till/no-till	1-80	1-160	55.20	8.20	63.40
750 acres					
Mb plow/chisel	1-120, 1-80	1-160	59.40	13.40	72.80
Chisel/disk	1-120, 1-80	1-160	58.80	10.50	69.30
Disk/field cultivator	2-80	1-160	50.70	11.50	62.20
No-till/no-till	1-80	1-160	42.80	7.50	50.30
1,000 acres					
Mb plow/chisel	1-160, 1-100	1-220	59.10	8.40	67.50
Chisel/disk	1-160, 1-100	1-220	55.70	7.00	62.70
Disk/field cultivator	1-160, 1-100	1-220	54.30	6.80	61.10
No-till/no-till	1-140	1-190	42.00	5.40	47.40

Table 12.08. Estimated Machinery-Related Costs for Various Corn and Soybean Farm Sizes and Tillage Systems[a] (cont.)

Farm size and tillage system[b]	Tractors (no.-Hp)	Combines (no.-Hp)	Costs ($/acre)		
			Machinery	Labor[c]	Total
Corn planted and soybeans drilled (cont.)					
1,500 acres					
Mb plow/chisel	1-240, 1-160	1-275	54.30	6.20	60.50
Chisel/disk	1-180, 1-140	1-275	47.70	5.80	53.50
Disk/field cultivator	1-180, 1-140	1-275	46.50	5.50	52.00
No-till/no-till	1-140, 1-100	1-275	37.90	3.90	41.80
2,000 acres					
Mb plow/chisel	2-200, 1-160	1-275	54.80	6.40	61.20
Chisel/disk	2-180, 1-160	1-275	49.30	5.50	54.80
Disk/field cultivator	2-180, 1-160	1-275	49.20	5.10	54.30
No-till/no-till	1-160, 1-120	1-275	38.30	3.50	41.80

[a] Optimum sizes and numbers of tractors with matched implements and combines with attached headers were determined and costs estimated using a computerized Farm Machinery Selection Program. These sizes and numbers should be regarded as the minimums to perform the operations in a timely manner. Costs for applying potassium and phosphorus fertilizers, herbicides, and lime are not included.
[b] Corn-soybean rotation assumed. Operations for each tillage system are given in Table 12.07.
[c] Labor assumed to cost $10 per hour.

Author

John C. Siemens
Department of Agricultural Engineering

Chapter 13. No Tillage

No-till is a system in which the soil is left undisturbed. The only soil disturbance is of a narrow band by soil-engaging components of the planter or drill. In addition to double-disk seed furrow openers and press wheels or firming wheels, soil-engaging components often include row cleaners, coulters, or other devices attached to the planter or drill.

No-till is very effective in reducing the potential for soil erosion due to wind and water. With no-till, the maximum amount of plant residue remains on the soil surface compared to other tillage systems. Surface residue protects the soil from raindrop impact and thus reduces splash erosion. In addition, surface residue slows the speed of water flowing down a slope, allowing more time for the water to infiltrate into the soil.

The trend toward no-till management for crop production in Illinois has accelerated since adoption of the 1985 Food Security Act. Provisions of the act require farmers to develop and apply an approved conservation plan on highly erodible fields. Many plans include the use of the no-till system. In addition, many farmers are adopting the no-till because they find it to be cost-effective.

No-Till Planters

No-till planters are specifically designed to plant in undisturbed soil with a high percentage of the surface covered with residue. In addition to field conditions, planter performance is influenced by planter features, attachments, adjustment, and operation. Successful planting in residue-covered and undisturbed fields depends on planter weight and appropriate down-pressure springs to transfer the weight to the planting units and other soil-engaging components in order to cut the residue and achieve adequate soil penetration.

Row-Cleaning Devices

A pair of spoked wheels is the most popular row cleaner design. In light residue, such as when following soybeans, it is questionable whether a row cleaner is necessary.

Row cleaners should be adjusted to remove only the residue from the row area and not a large amount of soil.

In heavy surface residue, use of row cleaners to move residue away from the row aids in soil warming and may improve seed placement and stand establishment. Early soil warming contributes to faster early growth, especially in poorly drained soils. Early soil warming also reduces disease pressure. Several plant pathogens, especially fungal pathogens such as Pythium species, are favored by cool, wet soils that occur under no-till. When combined with fungicide treatments, the use of row cleaners should result in more vigorous and uniform seedling emergence.

Row cleaners may also be beneficial in reducing the toxic effects of allelopathy. The potential for allelopathy occurs when the toxins and bacteria from decaying residue affect growth of new plants. The toxic effect is most likely to occur when crops are not rotated—for example, when corn follows corn.

Coulters

A coulter is usually mounted in front of each row unit of a no-till planter. The coulter is primarily for cutting through the residue and loosening the soil in the row to planting depth. It has little effect on soil warming or allelopathy. Coulter operating depth in relation to seeding depth is more consistent when the coulter is mounted on the planter unit rather than on a separate toolbar.

Several types of coulters are available for no-till planters (Figure 13.01). The most commonly used is the ¾- or 1-inch-wide fluted coulter. Generally, wider coulters increase tillage action and require more weight for penetration; a total weight of 400 to 600 pounds per coulter may be required. Wider coulters also may throw excessive amounts of soil from the row, especially when operated at higher planting speeds.

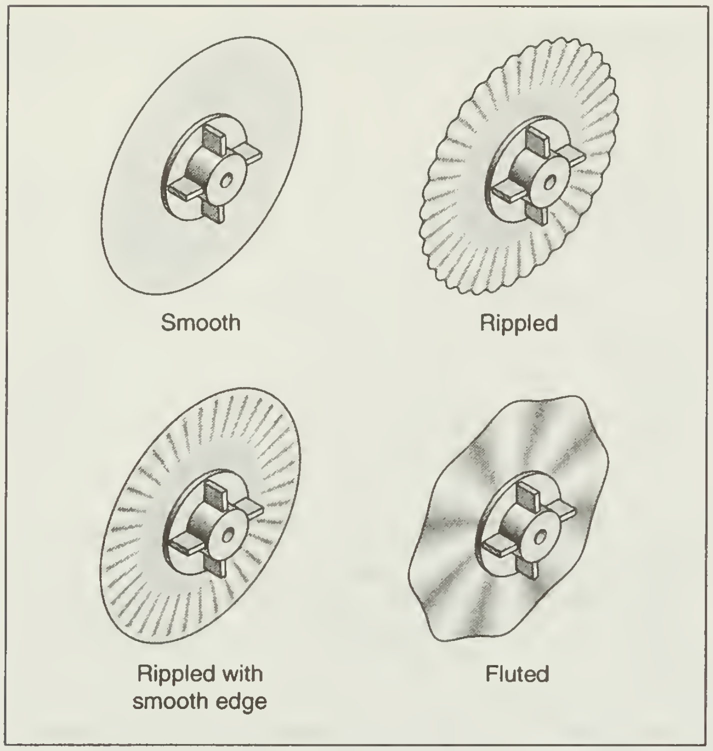

Figure 13.01. Common coulter styles.

Compared to fluted coulters, rippled or smooth coulters perform less tillage, require less weight for penetration, allow higher planting speeds, and are preferred for cutting residue.

Seed Furrow Openers

Seed furrow openers create well-defined slits in the soil where seed is placed at the desired depth. Planters are commonly equipped with either the double-disk or staggered double-disk seed furrow openers.

The staggered double-disk opener is a modification of the double-disk version. The leading edge of one disk, slightly in front of the other, provides a definite cutting edge. The trailing disk helps open the seed furrow. Planters with staggered double-disk seed furrow openers may not require as much weight to achieve soil penetration, especially if operated without a leading coulter. The double-disk opener will satisfactorily cut well-distributed soybean residue and penetrate a soft soil without a leading coulter. Research indicates no difference in seed spacing uniformity due to the type of opener.

Seed Covering

Good seed-to-soil contact is essential for seed germination and seedling emergence. A narrow press wheel or seed firmer can be attached to planters to improve seed-to-soil contact. This wheel operates just behind the seed furrow opener and presses the seed into the bottom of the furrow.

Commonly used seed covering devices include a small disk blade on each side of the row, a press wheel, an angled wheel on each side of the row, or a combination of these. Currently, there is no combination of covering devices and press wheels that has proven to offer a distinct advantage across all soil conditions.

Weight and Down-Pressure Springs

Additional weight is usually required on no-till planters to achieve uniform soil penetration. Down-pressure springs, which transfer weight from the toolbar to the row units, are usually located on the parallel linkage supporting the row units and may need tightening to achieve adequate penetration of the soil-engaging components. For no-till planting in hard soil conditions, heavy-duty down-pressure springs may be required in addition to extra weight.

Down pressure must be sufficient to cause the soil-engaging components to function properly and maintain a uniform planting depth. However, the planter must be heavy enough to prevent the springs from lifting too much weight from the seed-metering drive wheels, causing excessive wheel slippage and lower seeding rate.

The operator's manual serves as a guide for setting the planter. Final adjustments, such as planting depth and seeding rate, should be made in the field. Also, soil penetration and residue cutting should be checked in the field and appropriate adjustments made to ensure proper seed placement and to enhance seed-to-soil contact.

Strip Till

Long-term research and farmer experience in the Midwest show that traditional no-till planting (using planters with one no-till coulter in front of each row) usually maintains yield potential on well-drained and very low organic matter soils. However, in some cases, no-till planting may have a yield disadvantage compared to full-width tillage systems. One or more of the following conditions are usually associated with reduced no-till yields: heavy residue levels, poor soil drainage, cool soil temperatures, very early planting, uneven residue distribution, or an uneven soil surface. Such conditions can result in reduced stand, uneven emergence, slow early-season growth, and delayed maturity—all potential yield-limiting factors. These negative factors reduce corn yield more than soybean yield, since soybeans have a greater ability to

overcome early-season stress and to compensate for reduced stand.

To offset some of the limitations of traditional no-till planting, many farmers are now using spiked wheels as a planter attachment to prepare a residue-free strip for each row. Another method for improving the in-row area is to use strip till. Strip till is a system whereby a narrow strip is tilled, either at planting or before planting in early spring or the previous fall. One method involves equipping each planter row with two or three staggered, nonpowered fluted coulters that loosen soil and partially incorporate residue in a 6- to 8-inch band ahead of planter units. Staggered coulters and spiked wheels are often used on the same planter. Another method of loosening soil includes the use of powered rotary tillers set for strip tillage, either before planting or with the planter.

A new form of strip tillage involves planting in the tilled strips created by an anhydrous ammonia applicator equipped with special attachments. The attachments include a coulter mounted in front of each knife to cut residue; each knife is equipped with a "sealing wing" or "mole knife" and is followed by a pair of sealing disks. The goal is to form small ridges in which the crop will be planted. It is common for anhydrous ammonia to be applied as the ridges are formed. Attachments are also available to inject P and K in the same operation. If anhydrous ammonia is applied in the strip prepared for planting, the operation should be done in the fall to reduce the potential for ammonia injury to corn seedlings that often occurs if applied in the spring.

Studies in the northern Corn Belt show an advantage for residue-free rows for corn. In central Iowa, maintaining a residue-free band for the row regained about 80 percent of the yield loss for no-till compared to a clean-tilled seedbed for continuous corn. In Minnesota, residue removal from the row area was beneficial for no-till corn. However, with the longer growing season in Kentucky, removing residue from the row area increased continuous corn yield only one year out of four. Most research has shown only a small growth or yield response to residue removal or strip tillage compared to traditional no-till planting of corn in soybean residue.

Since the equipment for most strip tillage methods including an anhydrous ammonia applicator do a considerable amount of tillage, the potential for serious soil erosion may increase compared to traditional no-till, especially if rows run up and down slope. The problem may be especially critical on highly erodable fields following soybeans.

No-Till Drills

Erosion control is improved when soybeans are drilled in row spacings of 10 inches or less, which also provides a nearly equidistant plant spacing, resulting in greater yield potential. Narrow rows form a full canopy sooner, shading the soil earlier and reducing weed pressure. No-till drilling a crop leaves the field relatively smooth for easier harvesting and for no-tilling the following crop. It is difficult to obtain consistent depth of planting and uniform stand establishment in a field that has a rough surface, which may have been caused by previous wheel traffic, small ridges created by tillage, a planter, a row cultivator, or erosion.

Soil-engaging components of no-till drills are much like those on no-till planters. They must be able to cut and handle large amounts of residue, penetrate the soil, and establish good seed-to-soil contact.

There are two basic types of no-till drills: converted drills (conventional drills equipped with double-disk seed furrow openers to which a gang of coulters has been added) and drills designed specifically for no-till. For many situations, either type may provide satisfactory performance. However, in fields with heavy

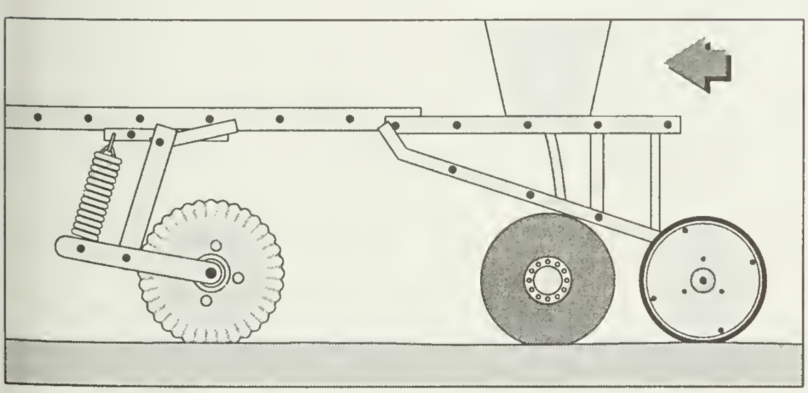

Figure 13.02. Drill mounted on a coulter cart.

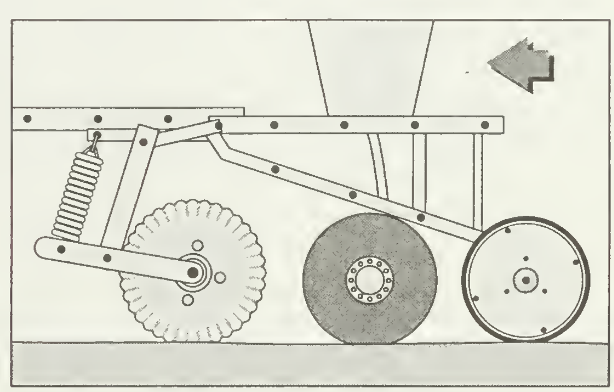

Figure 13.03. No-till drill with coulters.

residue and hard surface soils—and in large-scale operations—a drill designed specifically for no-till can probably be justified.

A converted drill (Figure 13.02) is usually a three-point mounted conventional drill on a wheeled carrier, equipped with a coulter positioned in front of each double-disk seed furrow opener. Ripple or fluted coulters are commonly used (Figure 13.01). Weight may need to be added to the carrier for sufficient penetration of the coulters. It is important for the seed openers to track in the coulter slots.

Drills designed specifically for no-till (Figure 13.03) have all soil-engaging components on a single unit. In hard soil conditions, additional weight may be needed to help ensure penetration by these components. On some no-till drills, the openers are staggered to allow improved residue flow.

Individual openers should have sufficient down-pressure and independent depth control with enough vertical movement to allow all rows to operate at the desired depth. Depth control is more consistent if fields are smooth.

Some no-till drills are not equipped with coulters but use the seed furrow openers to cut the residue andpenetrate the soil to seeding depth. These drills often use staggered double-disk seed furrow openers without a coulter in front. On these drills, the leading disk, usually about ½ to 1 inch in front of the other, cuts the residue, and the following disk aids in opening the seed furrow. At least one brand of drill uses a large-diameter single disk set at a slight angle to cut through the residue and serve as a seed furrow opener. This design provides for minimal soil disturbance and requires less weight for penetration.

Spacing, Weight, and Down Pressure

A wider row spacing (10 or 12 inches rather than 7 or 8) on a no-till drill provides more clearance for residue flow and requires less weight per unit of drill width for soil penetration.

Depending on coulter type and width, opener design, and field conditions, up to 600 pounds per row may be needed on a drill to provide for adequate penetration. Down-pressure springs on individual rows must transfer enough weight from the drill frame for all soil-engaging components to function as intended. Coulters and seed furrow openers should operate at the desired seed-depth setting. Depth control devices and seed-press wheels must be in firm contact with the soil. As the springs are tightened, especially in hard soil conditions, they may physically lift the drive mechanism of the drill off the ground, causing a reduced seeding rate due to wheel slippage. In such conditions, extra weight on the drill frame may solve the problem.

Press Wheels and Depth Control

With a converted drill, depth of seed placement may be controlled by the depth of the coulter gang or by the press wheels behind each seed opener. When seeding depth is controlled by the coulters, seed-to-soil contact is obtained with a narrow press wheel running directly over the seed. Using this method, extra weight or heavy down-pressure springs are not needed for the seed furrow openers, but extra weight or load may be needed on the coulter carrier. A harrow behind the drill is often used to improve seed coverage.

Several no-till drills use coulters to cut residue and use both the coulters and seed furrow openers to loosen a strip of soil. A wide press wheel mounted behind each of the seed furrow openers controls depth. Total weight and down-pressure springs must be sufficient to force the coulters and openers into the soil the desired planting depth and keep adequate pressure on the press wheels. The press wheels must be wide enough to ride on firm soil adjacent to the seed furrow in order to gauge seeding depth and help cover the seed.

Another option for no-till drills is the use of a pair of angled press wheels behind each opener to control planting depth. Clearance between adjacent rows may prevent the use of angled press wheels in large amounts of residue.

General Operation

No-till drills must be heavier than conventional drills. Enough weight and sufficient down-pressure springs are needed to cause the soil-engaging components to function properly. Weight is essential for cutting residue and penetrating soil. Adequate weight also keeps the depth control wheels, the seed press wheels, and the drive mechanism in firm contact with the soil.

More tractor power is required to lift and pull the greater weight of a no-till drill, especially at high operating speeds. High operating speeds may assist residue flow but also may sacrifice some seed depth uniformity.

Residue flow through the drill is better if the residue is not shredded. When residue is standing and attached to the soil, less of it has to be cut by the drill, and the soil holds the residue as the drill passes through it. Leaving concentrations of residue in the field at harvest should be avoided; well-distributed residue provides better erosion control and passes through a drill better. A chaff spreader, especially for combines with wide headers, is important.

Weed Control

No-till systems require a well-designed weed control program, including proper timing and accurate application of herbicides. Effective programs are available that include the application of herbicides as early preplant, burndown, preemergence, and postemergence.

Early Preplant Plus Preemergence or Postemergence

Early weed growth may be successfully controlled by applying an early preplant (EPP) herbicide. An EPP herbicide is usually applied prior to the germination of most weed seed. However, if the EPP herbicide has postemergence activity or foliar activity, it can effectively control small emerged weeds. EPP herbicides, such as Extrazine for corn and Canopy for soybeans, can provide both burndown and residual control. However, with some herbicides it is often preferable to use a treatment including Roundup plus 2,4-D for improved control of existing vegetation.

An EPP herbicide application is unlikely to provide season-long weed control, especially if the application is made relatively early or if the soil is disturbed significantly during the planting application. An additional herbicide treatment may be needed. One option is to use a split application, with one portion applied EPP and the other soon after planting. Another option is to apply an EPP treatment and follow up with a postemergence herbicide program.

The EPP program has several advantages. Performance is usually excellent when a herbicide is applied in March or early April because cool weather and spring rains enhance performance. Also, the expense of a "burndown herbicide" may be eliminated. The main disadvantage of EPP programs is that for late-planted crops, preemergence or postemergence treatments may be needed to maintain season-long control.

Burndown Plus Preemergence or Postemergence

With no-till, weeds established prior to planting and weeds that emerge later must all be controlled. Weeds established before planting can be controlled with "burndown" herbicides, such as Roundup and Gramoxone Extra. With early planting, especially of corn, there may be no weeds present, and a burndown herbicide may not be needed. Emerged weeds, if small, may also be controlled by some preemergence herbicides applied at planting. If preemergence herbicides are not used, several excellent postemergence herbicides are available. The type of herbicide selected and the application rate will depend on the type of vegetation present and the crop.

See the section titled "Conservation Tillage and Weed Control" in Chapter 15 and University of Illinois College of Agriculture Circular 1306, *Weed Control Systems for Lo-Till and No-Till* for additional information on weed control using a no-till system.

Fertilizer Management

Since soils are cooler, wetter, and less well-aerated with no-till, the ability of crops to utilize nutrients may be altered and adjustments in fertilizer management may be important.

Stratification of immobile nutrients, such as phosphorus and potassium, with high concentrations near the soil surface and decreasing concentrations with depth, has been routinely observed where no-till and other conservation tillage systems (such as disk and chisel plow) have been used for at least 3 to 4 years. This stratification results from both the addition of fertilizer to the soil surface and the "cycling" of nutrients by plants. Plant roots uptake nutrients from well below the soil surface; some of these nutrients are then deposited on the soil surface in the form of crop residue.

When soil moisture is adequate, nutrient stratification has not been found to decrease nutrient availability because root activity in the fertile zone near the soil surface is sufficient to supply plant needs. The residue enhances root activity near the soil surface by reducing evaporation of water, which helps keep the surface soil moist and cool. If the surface dries out and the shallow roots become inactive, nutrient uptake could be reduced, especially if the lower portions of the old plow layer are most likely to be the areas of lower fertility.

Details on fertility are covered in Chapter 11, "Soil Testing and Fertility." The key points on fertility management for no-till are as follows:

A. Liming to neutralize soil acidity is important, especially with surface applications of nitrogen (N) fertilizer. Lime rates may need to be adjusted and applications more frequent with no-till. Where possible, lime should be incorporated as needed prior to establishing a no-till system.

B. Any phosphorus and potassium deficiencies should be corrected prior to switching to no-till because surface applications move deeper into the soil very slowly.

C. After several years of no-till, it may be desirable to take samples for nutrient analysis from near the

soil surface (0 to 3 inches deep) and from lower portions of the old tillage zone (3 to 7 inches deep). If depletion of nutrients or accumulation of acidity in the lower portion occurs and crops show nutrient deficiency, moldboard or chisel plowing can correct the stratification problem.

D. Starter fertilizer appears to be more important with no-till, especially for continuous corn. More information on the use of starter for no-till is provided in Chapter 11.

E. Nitrogen management is very important to success with no-till planting of corn. Anhydrous ammonia applied in the spring before planting can severely injure or kill seedlings if corn is planted directly above it. Anhydrous ammonia can safely be applied in the fall (sidedressed after planting) or in the spring before planting (between rows to be planted). If rain is not received within 3 days after application, there is a potential for loss of a portion of the nitrogen surface applied on no-till in the form of urea or urea–ammonium nitrate solutions. To minimize this loss potential, apply these products 1 to 2 days ahead of a rain, or use a urease inhibitor.

Soil Density

Untilled soil usually has more density (weight per unit volume) and less air space than tilled soil. The density of tilled soil is lower after primary tillage, but with secondary tillage, wheel traffic, and several wetting and drying periods, it becomes nearly equal in density to untilled soil by harvest.

Soil densities greater than 1.4 to 1.6 g/cc have been shown to restrict root growth when rainfall is either more or less than optimum. With no-till, soil density sometimes reaches this critical level. High soil density may also reduce soil drainage, soil aeration, and fertilizer uptake, while increasing the potential for herbicide injury.

Over time, however, changes occur in the soil under no-till which may improve the effect of dense soil on plant rooting: organic matter near the soil surface may improve aggregation and air movement in the soil, and old root channels and earthworm burrows remain as undisturbed pathways for new roots. Thus high soil density, which may limit rooting in tilled soil, may not have the same effect in continuous no-till.

Excessive compaction can cause yield decreases when too much or too little soil moisture is available. With too much water, compaction reduces drainage, causes denitrification, and limits the availability of oxygen to the roots. With too little moisture, the root system must seek moisture from the subsoil, and excessive compaction may prevent the roots from getting to that moisture.

Soil Organic Matter and Aggregation

Soil organic matter content tends to stabilize at a certain level with any tillage system and crop rotation. With no-till, partially decayed plant material tends to concentrate near the soil surface because the residue is left on the surface and plant roots tend to be more numerous near the surface.

Continuous no-till leads to better soil aggregation. A high level of aggregation indicates good soil structure, which improves plant emergence and rooting, aeration, drainage, and water infiltration. Good soil structure also decreases the susceptibility of soil to compaction.

An Indiana study showed that after 5 years of continuous no-till corn, aggregation in the top 2 inches of soil was increased. However, moldboard plowing the plots returned the aggregation index near the soil surface to its original level.

Earthworm and Root Channels

Physical properties of soil are not determined solely by mechanical manipulations of the soil or by surface residue. Biological populations can significantly improve soil physical conditions important to plant growth and may play a significant role in maintaining good soil tilth in the absence of tillage.

Channels for water movement and rooting are provided by earthworms and roots of previous crops. Tillage tends to reduce earthworm populations by speeding soil drying and freezing rates, disrupting earthworm burrows, and burying the plant residue that worms use for food. Much more research is needed to explain all of the impact of no-till on soil biology.

Soil Drainage

Research and farmer experiences during the past 20 years have shown that no-till may increase crop yields on soils with no drainage problems. Improving drainage on poorly drained soil improves crop performance, especially with no-till.

Alleviating Soil Compaction

Problems such as compacted layers or "tillage pans," excessive traffic areas, ruts from wheel traffic, and livestock trails are troublesome with no-till. Compacted layers from previous plowing and disking

can limit rooting. Natural soil processes such as freezing and thawing, wetting and drying, and the channeling of earthworms and roots eventually loosen or reduce the effects of compacted zones under no-till, but these processes are slow. The use of a chisel plow or subsoiler before beginning no-till should speed the process if compaction is not reintroduced by subsequent traffic and excessive secondary tillage. Benefits from subsoiling can generally be expected only when it disrupts or loosens a drainage- or root-restricting layer. The disruption allows excess water to drain and plant roots to explore a greater volume of soil.

Some soils have a natural hardpan or claypan at a depth of 12 to 18 inches. Generally, the layers below the pan are also compacted and poorly drained. In such cases, chiseling or subsoiling is ineffective because it is impossible to break through to a better-drained layer.

Soil surface compaction and non-uniformity from wheel or livestock traffic can cause uneven seed placement and poor stands in no-till. To the extent possible, no-till fields should be kept smooth. Where the soil surface is not smooth, shallow tillage may be needed to obtain uniform seed placement.

Crop Rotation

In general, crop rotation improves chances for success with no-till. Several long-term studies show that a corn/soybean rotation improves the yield potential of no-till corn compared to continuous corn. With continuous no-till corn, several factors—including lower soil temperature and allelopathy—may cause the lower yield potential. Lower yields have been especially evident on poorly drained soil and high organic-matter soils.

Small grains such as wheat and rye germinate at a much lower soil temperature than corn (32°F versus 55°F), but they also benefit from crop rotation when residue is left on the soil surface. For small grains, the deleterious effects from monoculture are most likely due to allelopathy and disease buildup.

The use of row cleaners may improve the germination, early growth rate, and potential yield of no-till crops planted without rotation.

Author

John C. Siemens
Department of Agricultural Engineering

Adaptability of No-Till to Specific Locations

Soil, climate, and crop rotation influence the success of no-till. In addition, success is influenced by pest control, fertility practices, and management experience of the farm operator. The decision to adopt no-till may be based on net return, potential for reduced soil erosion, or eligibility for government programs. Yield potential of crops grown with no-till is an important consideration.

Several states have classified soils into tillage management groups for corn and soybean production. Soil types are grouped according to unique soil properties and their influence on crop yield with no-till planting. Soil characteristics include drainage, texture, organic matter, and slope. A summary of the classification as might be applied to Illinois follows:

A. *Equal yield.* In central and northern Illinois, when crops are rotated and when no-till is used on naturally well-drained soils, or on slopes greater than 6 percent, no-till should provide yield potential equal to that of other systems for corn, soybeans, and wheat.

B. *Higher yield.* In southern Illinois, with crop rotation, well-drained soil, slope greater than 6 percent, or very low organic-matter soil, no-till should provide a higher yield potential than other tillage systems.

C. *Higher yield.* In southern Illinois, on light (very low organic matter), somewhat poorly drained, and poorly drained silt loams (that are nearly level to gently sloping and overlie very slowly permeable fragipan-like soil layers that restrict plant rooting and water movement), no-till yield potential should be higher than with other tillage systems.

D. *Lower yield.* On dark, poorly drained silty clay loams to clay soils with 0 to 2 percent slope, slightly lower yields are expected with no-till compared to other tillage systems.

An established sod or cover crop must be managed to avoid excessive water use and mouse and mole problems prior to no-till planting corn or other grain crop.

Chapter 14. Water Management

A superior water-management program seeks to provide an optimum balance of water and air in the soil, which allows full expression of genetic potential in plants. The differences among poor, average, and record crop yields generally can be attributed to the amount and timing of the soil's water supply.

Improving water management is an important way to increase crop yields. By eliminating crop-water stress, you obtain more benefits from improved cultural practices and realize the full yield of the cultivars now available.

To produce maximum yields, the soil must be able to provide water as it is needed by the crop. But the soil seldom has just the right amount of water for maximum crop production; a deficiency or a surplus usually exists. A good water-management program seeks to avoid both extremes through a variety of measures. These measures include draining waterlogged soils; making more effective use of the water-holding capacity of soils so that crops will grow during periods of insufficient rainfall; increasing the soil's ability to absorb moisture and conduct it down through the soil profile; reducing water loss from the soil surface; and irrigating soils with low water-holding capacity.

In Illinois, the most frequent water-management need is improved drainage. Initial efforts in the nineteenth century to artificially drain Illinois farmland made our soils among the most productive in the world. Excessive water in the soil limits the amount of oxygen available to plants and thus retards growth. This problem occurs where the water table is high or where water ponds on the soil surface. Removing excess water from the root zone is an important first step toward a good water-management program. A drainage system should be able to remove water from the soil surface and lower the water table to about 12 inches beneath the soil surface in 24 hours and to 21 inches in 48 hours.

The Benefits of Drainage

A well-planned drainage system will provide a number of benefits: better soil aeration, more timely field operations, less flooding in low areas, higher soil temperatures, less surface runoff, better soil structure, better incorporation of herbicides, better root development, higher yields, and improved crop quality.

Soil aeration. Good drainage ensures that roots receive enough oxygen to develop properly. When the soil becomes waterlogged, aeration is impeded and the amount of oxygen available is decreased. Oxygen deficiency reduces root respiration and often the total volume of roots developed. It also impedes the transport of water and nutrients through the roots. The roots of most nonaquatic plants are injured by oxygen deficiency, and prolonged deficiency may result in the death of some cells, entire roots, or in extreme cases the whole plant. Proper soil aeration also will prevent rapid losses of nitrogen to the atmosphere through denitrification.

Timeliness. Because a good drainage system increases the number of days available for planting and harvesting, it can enable you to make more timely field operations. Drainage can reduce planting delays and the risk that good crops will be drowned or left standing in fields that are too wet for harvest. Good drainage may also reduce the need for additional equipment that is sometimes necessary to speed up planting when fields stay wet for long periods.

Soil temperature. Drainage can increase soil surface temperatures during the early months of the growing season by 6° to 12°F. Warmer temperatures assist germination and increase plant growth.

Surface runoff. By enabling the soil to absorb and store rainfall more effectively, drainage reduces runoff from the soil surface and thus reduces soil erosion.

Soil structure. Good drainage is essential in maintaining the structure of the soil. Without adequate

drainage the soil remains saturated, precluding the normal wetting and drying cycle and the corresponding shrinking and swelling of the soil. The structure of saturated soil will suffer further damage if tillage or harvesting operations are performed on it.

Herbicide incorporation. Good drainage can help avoid costly delays in applying herbicide, particularly postemergence herbicides. Because some herbicides must be applied during the short time that weeds are still relatively small, an adequate drainage system may be necessary for timely application. Drainage may also help relieve the cool, wet-stress conditions that increase crop injury by some herbicides.

Root development. Good drainage enables plants to send roots deeper into the soil so they can extract moisture and nutrients from a larger volume of soil. Plants with deep roots are better able to withstand drought.

Crop yield and quality. All of the benefits previously mentioned contribute to greater yields of higher-quality crops. The exact amount of the yield and quality increases depends on the type of soil, the amount of rainfall, the fertility of the soil, crop-management practices, and the level of drainage before and after improvements are made. Of the few studies that have been conducted to determine the benefits of drainage, the most extensive in Illinois was initiated at the Agronomy Research Center at Brownstown. This study evaluated drainage and irrigation treatments with Cisne and Hoyleton silt loams.

Drainage Methods

A drainage system may consist of surface drainage, subsurface drainage, or some combination of both. The kind of system you need depends in part upon the ability of the soil to transmit water. The selection of a drainage system ultimately should be based on economics. Surface drainage, for example, would be most appropriate where soils are impermeable and would therefore require too many subsurface drains to be economically feasible. Soils of this type are common in southern Illinois.

Surface Drainage

A surface drainage system is most appropriate on flat land with slow infiltration and low permeability and on soils with restrictive layers close to the surface. This type of system removes excess water from the soil surface through improved natural channels, human-made ditches, and shaping of the land surface. A properly planned system eliminates ponding, prevents prolonged saturation, and accelerates the flow of water to an outlet without permitting siltation or soil erosion.

A surface drainage system consists of a farm main, field laterals, and field drains. The farm main is the outlet serving the entire farm. Where soil erosion is a problem, a surface drain or waterway covered with vegetation may serve as the farm main. Field laterals are the principal ditches that drain adjacent fields or areas on the farm. The laterals receive water from field drains, or sometimes from the surface of the field, and carry it to the farm main. Field drains are shallow, graded channels (with relatively flat side slopes) that collect water within a field.

A surface drainage system sometimes includes diversions and interceptor drains. Diversions are channels constructed across the slope of the land to intercept surface runoff and prevent it from overflowing bottomlands. Diversions are usually located at the bases of hills. These channels simplify and reduce the cost of drainage for bottomlands.

Interceptor drains collect subsurface flow before it resurfaces. These channels may also collect and remove surface water. They are used on long slopes that have grades of 1 percent or more and on shallow, permeable soils overlying relatively impermeable subsoils. The location and depth of these drains are determined from soil borings and the topography of the land.

The principal types of surface drainage configurations are the random and parallel systems (Figure 14.01). The **random system** consists of meandering field drains that connect the low spots in a field and provide an outlet for excess water. This system is adapted to slowly permeable soils with depressions too large to be eliminated by smoothing or shaping the land.

The **parallel system** is suitable for flat, poorly drained soils with many shallow depressions. In a field that is cultivated up and down a slope, parallel ditches can be arranged to break the field into shorter lengths. The excess water thus erodes less soil because it flows over a smaller part of the field before reaching a ditch. The side slopes of the parallel ditches should be flat enough to permit farm equipment to cross them. The spacing of the parallel ditches will vary according to the slope of the land.

For either the random or parallel systems to be fully effective, minor depressions and irregularities in the soil surface must be eliminated through land grading or smoothing.

Bedding is another surface drainage method that is used occasionally. The land is plowed to form a series of low, narrow ridges that are separated by parallel,

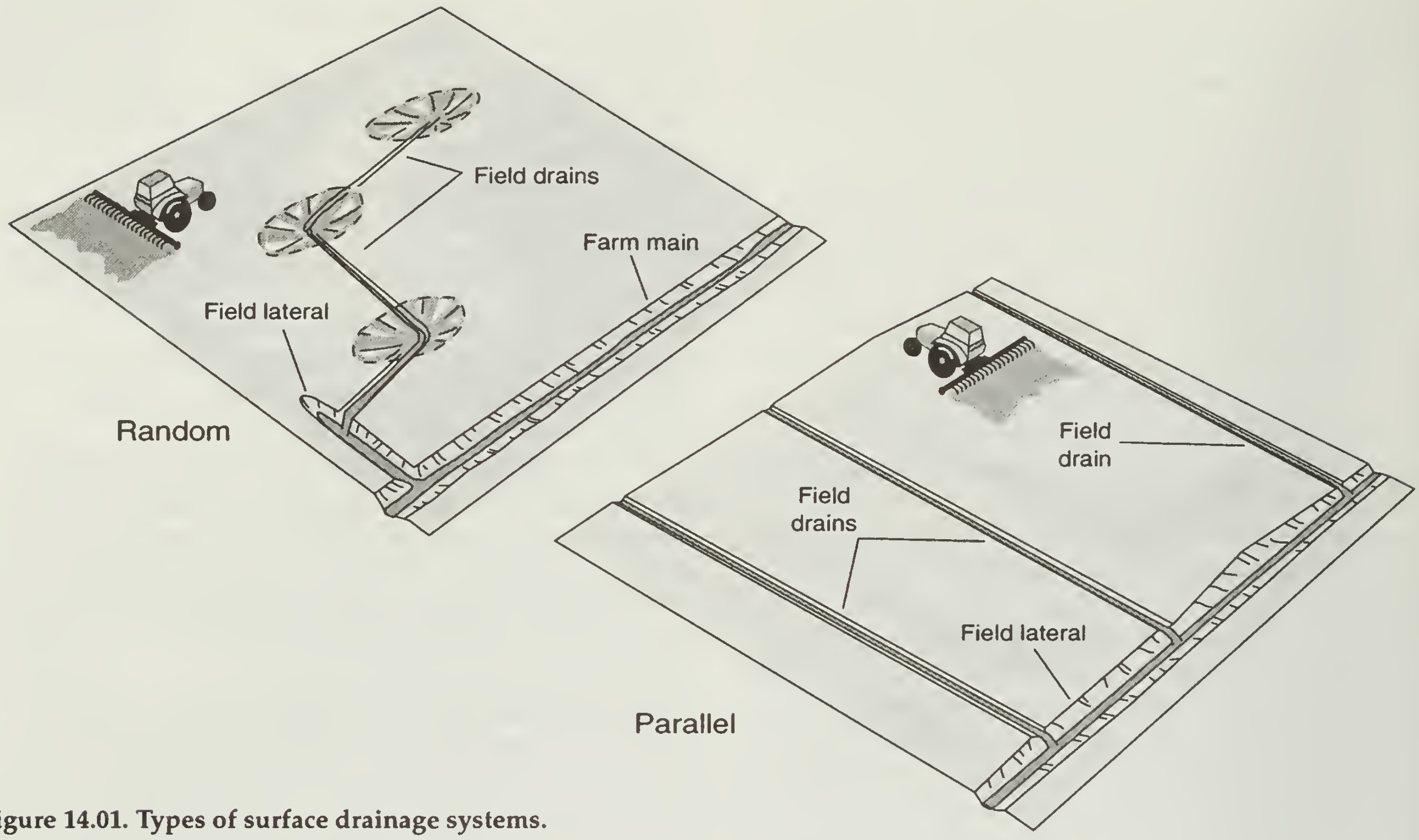

Figure 14.01. Types of surface drainage systems.

dead furrows. The ridges are oriented in the direction of the steepest slope in the field. Bedding is adapted to the same conditions as the parallel system, but it may interfere with farm operations and does not drain the land as completely. It is not generally suited for land that is planted in row crops because the rows adjacent to the dead furrows will not drain satisfactorily. Bedding is acceptable for hay and pasture crops, although it will cause some crop loss in and adjacent to the dead furrows.

Subsurface Drainage

Many of the deep, poorly drained soils of central and northern Illinois respond favorably to subsurface drainage. A subsurface drainage system is used in soils permeable enough that the drains do not have to be placed too closely together. If the spacing is too narrow, the system will not be economical. By the same token, the soil must be productive enough to justify the investment. Because a subsurface drainage system functions only as well as the outlet, a suitable one must be available or constructed. The topography of the fields also must be considered because the installation equipment has depth limitations and a minimum amount of soil cover is required over the drains.

Subsurface systems are made up of an outlet or main, sometimes a submain, and field laterals. The drains are placed underground, although the outlet is often a surface drainage ditch. Subsurface drainage conduits are constructed of clay, concrete, or plastic.

There are four types of subsurface systems: the random, the herringbone, the parallel, and the double-main (Figure 14.02). A single system or some combination of systems may be chosen according to the topography of the land.

For rolling land, **a random system** is recommended. With this system, the main drain is usually placed in a depression. If the wet areas are large, the submains and lateral drains for each area may be placed in a gridiron or herringbone pattern to achieve the required drainage.

With the **herringbone system**, the main or submain is often placed in a narrow depression or on the major slope of the land. The lateral drains are angled upstream on either side of the main. This system sometimes is combined with others to drain small or irregular areas. Because two laterals intersect the main at the same point, however, more drainage than necessary may occur at that intersection point. The herringbone system may also cost more because it requires more junctions. Nevertheless, it can provide

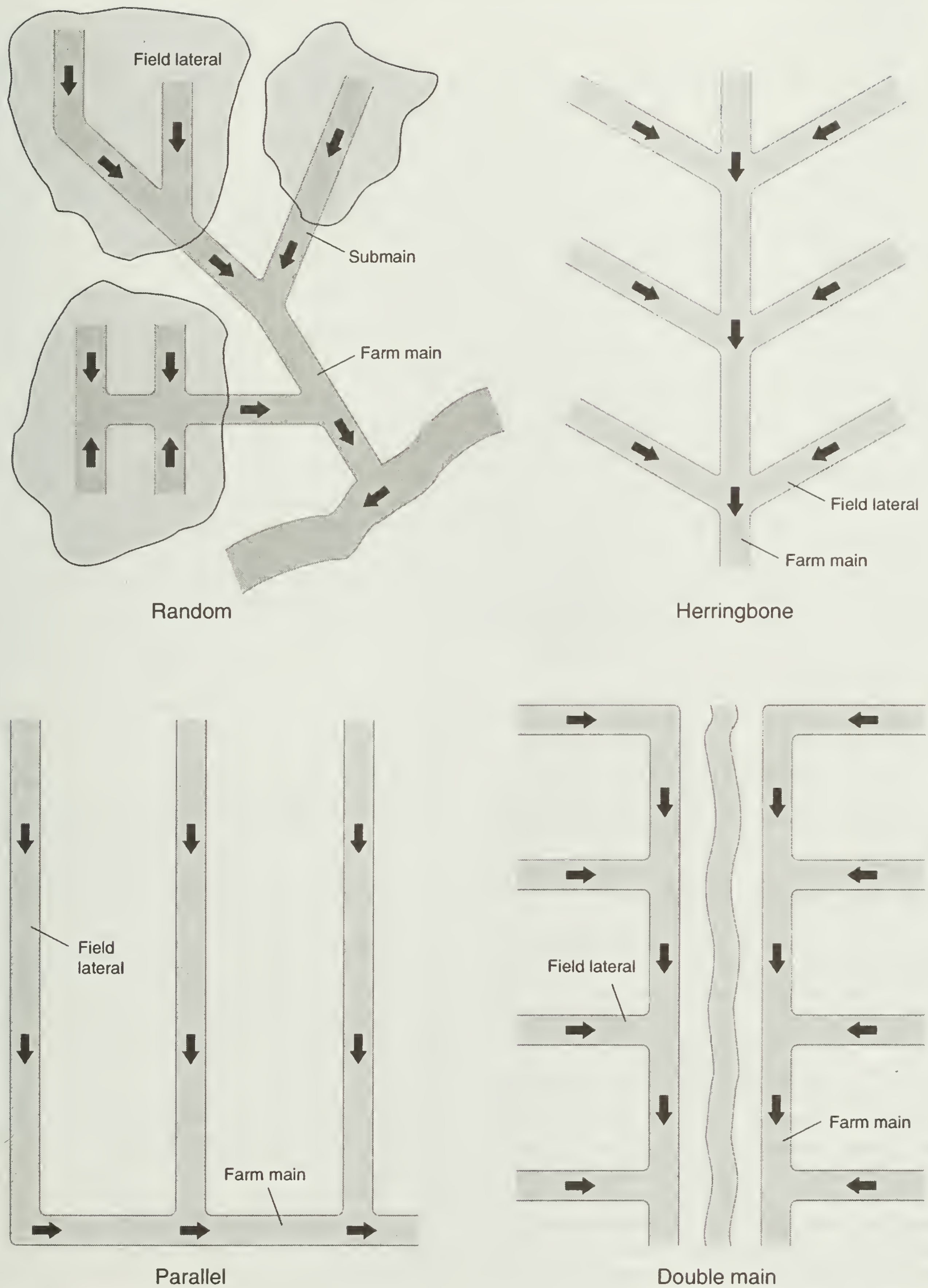

Figure 14.02. Types of subsurface drainage systems. The arrows indicate the direction of water flow.

the extra drainage needed for the heavier soils found in narrow depressions.

The **parallel system** is similar to the herringbone system, except that the laterals enter the main from only one side. This system is used on flat, regularly shaped fields and on uniform soil. Variations are often used with other patterns.

The **double-main system** is a modification of the parallel and herringbone systems. It is used where a depression, frequently a natural watercourse, divides the field in which drains are to be installed. Sometimes the depression may be wet due to seepage from higher ground. A main placed on either side of the depression intercepts the seepage water and provides an outlet for the laterals. If only one main were placed in the center of a deep and unusually wide depression, the grade of each lateral would have to be changed at some point before it reaches the main. A double-main system avoids this situation and keeps the grade lines of the laterals uniform.

The advantage of a subsurface drainage system is that it usually drains soil to a greater depth than surface drainage. Subsurface drains placed 36 to 48 inches deep and 80 to 100 feet apart are suitable for crop production on many medium-textured soils in Illinois. When properly installed, these drains require little maintenance, and because they are underground they do not obstruct field operations.

For more specific information about surface and subsurface drainage systems, obtain Circular 1226, *The Illinois Drainage Guide*, from your local Extension adviser. This publication discusses the planning, design, installation, and maintenance of drainage systems for a wide variety of soil, topographic, and climatic conditions.

Benefits of Irrigation

During an average year, most regions of Illinois receive ample rainfall for growing crops, but, as shown in Figure 14.03, rain does not occur when the crops need it the most. From May to early September, growing crops demand more water than is provided by precipitation. For adequate plant growth to continue during this period, the required amount of water must be supplied by stored soil water or by irrigation. During the growing season, crops on deep, fine-textured soils may draw upon moisture stored in the soil, if the normal amount of rainfall is received throughout the year. But if rainfall is seriously deficient or if the soil has little capacity for holding water, crop yield may be reduced. Yield reductions are likely to be most severe on sandy soils or soils with claypans. Claypan soils restrict root growth, and both types of soils often

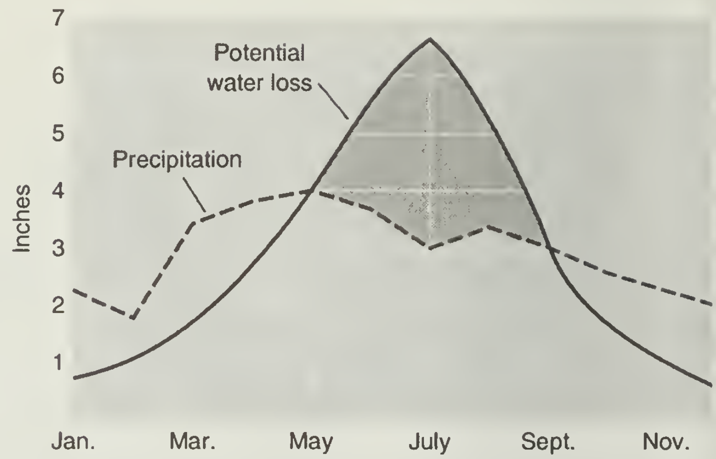

Figure 14.03. Average monthly precipitation and potential moisture loss from a growing crop in central Illinois.

cannot provide adequate water during the growing season.

To prevent crop water stress during the growing season, more and more producers are using irrigation. It may be appropriate where water stress can substantially reduce crop yields and where a supply of usable water is available at reasonable cost. Irrigation is still most widely used in the arid and semi-arid parts of the United States, but it can be beneficial in more humid states such as Illinois. Almost yearly, Illinois corn and soybean yields are limited by drought to some degree, even though the total annual precipitation exceeds the water lost through evaporation and transpiration (ET).

With current cultural practices, a good crop of corn or soybeans in Illinois needs at least 20 inches of water. All sections of the state average at least 15 inches of rain from May through August. Thus satisfactory yields require at least 5 inches of stored subsoil water in a normal year.

Crops growing on deep soil with high water-holding capacity, that is, fine-textured soil with high organic-matter content, may do quite well if precipitation is not appreciably below normal and if the soil is filled with water at the beginning of the season.

Sandy soils and soils with subsoil layers that restrict water movement and root growth cannot store as much as 5 inches of available water. Crops planted on these soils suffer from inadequate water every year. Most of the other soils in the state can hold more than 5 inches of available water in the crop-rooting zone. Crops on these soils may suffer from water deficiency when subsoil water is not fully recharged by about May 1 or when summer precipitation is appreciably below normal or poorly distributed throughout the season.

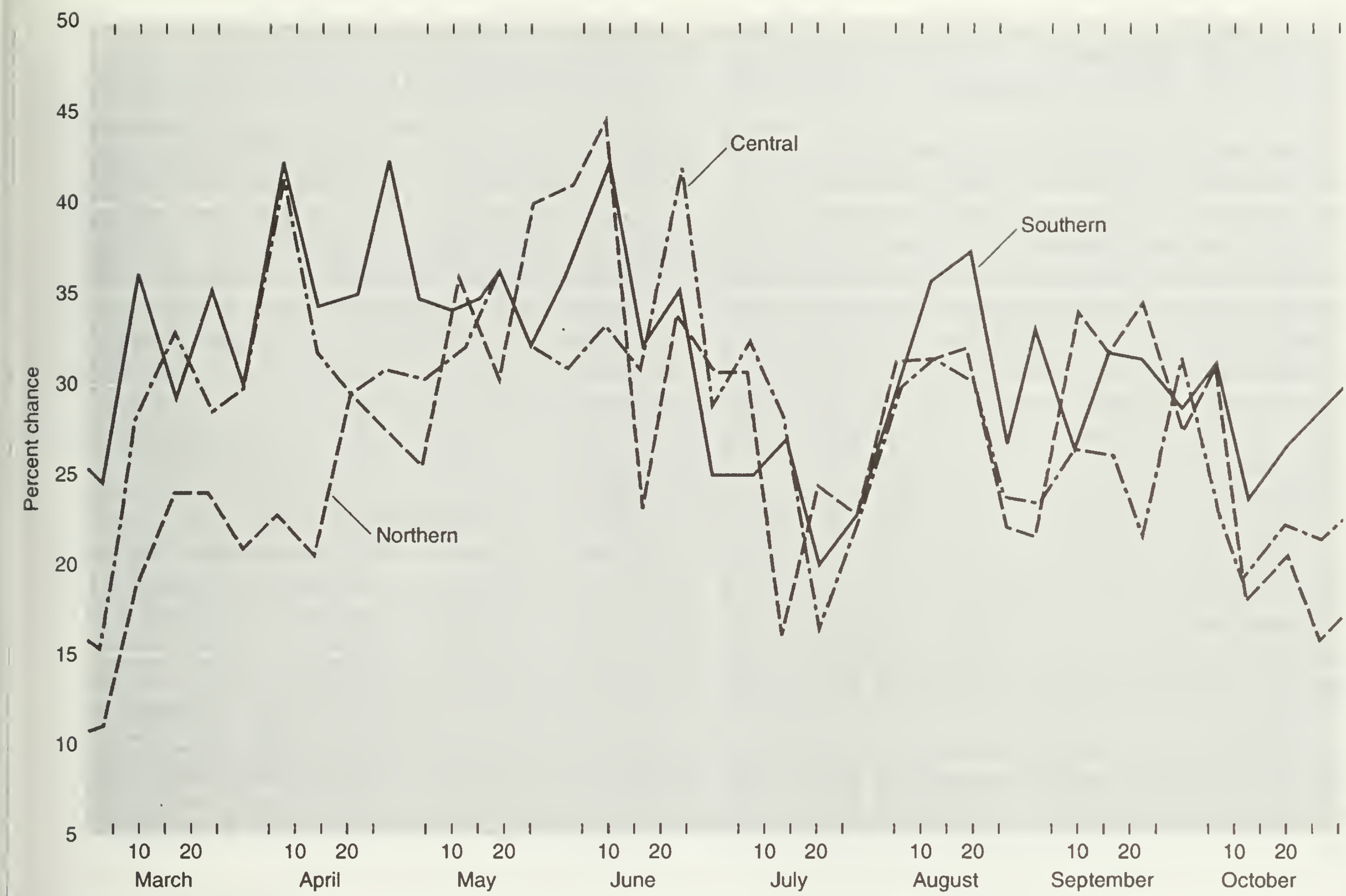

Figure 14.04. Chance of at least one inch of rain in Illinois in one week.

The probability of getting at least one inch of rain in any week is shown in Figure 14.04. One inch of rain per week will not replace ET losses during the summer, but it can keep crop-water stress from severely limiting final grain yields on soils that can hold water reasonably well. This probability is lowest in all sections of Illinois during July, when corn normally is pollinating and soybeans are flowering.

Water stress delays the emergence of corn silks and shortens the period of pollen shedding, thus reducing the time of overlap between the two processes. The result is incomplete kernel formation, which can have disastrous effects on corn yields.

Corn yields may be reduced by as much as 40 percent when visible wilting occurs on four consecutive days at the time of silk emergence. Studies have also shown that severe drought during the pod-filling stage causes similar yield reductions in soybeans.

Increasing numbers of farmers are installing irrigation systems to prevent the detrimental effects of water deficiency. Some years of below-normal summer rainfall and other years of erratic rainfall distribution throughout the season have contributed to the increase. As other yield-limiting factors are eliminated, adequate water becomes increasingly important to ensure top yields.

Most of the development of irrigation systems has occurred on sandy soils or other soils with correspondingly low levels of available water. Some installations have been made on deeper, fine-textured soils, and other farmers are considering irrigation of such soils.

Deciding to Irrigate

The need for an adequate water source cannot be overemphasized when one is considering irrigation. If a producer is convinced that an irrigation system will be profitable, an adequate source of water is necessary. Such sources do not exist now in many parts of the state. Fortunately, underground water resources are generally good in the sandy areas where irrigation is most likely to be needed. A relatively shallow well in some of these areas may provide enough water to

irrigate a quarter section of land. In some areas of Illinois, particularly the northern third, deeper wells may provide a relatively adequate source of irrigation water.

Some farmers pump their irrigation water from streams, a relatively good and economical source, if the stream does not dry up in a droughty year. Impounding surface water on an individual farm is also possible in some areas of the state, but this water source is practical only for small acreages. However, an appreciable loss may occur both from evaporation and from seepage into the substrata. Generally, 2 acre-inches of water should be stored for each acre-inch actually applied to the land.

A 1-inch application on 1 acre (1 acre-inch) requires 27,000 gallons of water. A flow of 450 gallons per minute provides 1 acre-inch per hour. Thus a 130-acre, center-pivot system with a flow of 900 gallons per minute can apply 1 inch of water over the entire field in 65 hours of operation. Because some of the water is lost to evaporation and some may be lost from deep percolation or runoff, the net amount added is less than 1 inch.

The Illinois State Water Survey and the Illinois State Geological Survey (both located in Urbana) can provide information about the availability of irrigation water. Submit a legal description of the site planned for development of a well and request information regarding its suitability for irrigation-well development. Once you decide to drill a well, the Water Use Act of 1983 requires you to notify the local Soil and Water Conservation District office if the well is planned for an expected or potential withdrawal rate of 100,000 gallons or more per day. There are no permit requirements or regulatory provisions.

An amendment passed in 1987 allows Soil and Water Conservation districts to limit the withdrawals from large wells if domestic wells meeting state standards are affected by localized drawdown. The legislation currently affects Kankakee, Iroquois, Tazewell, and McLean counties.

The Riparian Doctrine, which governs the use of surface waters, states that one is entitled to a reasonable use of the water that flows over or adjacent to his or her land as long as one does not interfere with someone else's right to use the water. No problem results as long as water is available for everybody. But when the amount of water becomes limited, legal determinations become necessary as to whether one's water use interferes with someone else's rights. It may be important to establish a legal record to verify the date on which the irrigation water use began.

Assuming that it will be profitable to irrigate and that an assured supply of water is available, how do you find out what type of equipment is available and what is best for your situation? University representatives have discussed this question in various meetings around the state, although they cannot design a system for each individual farm. Your local Extension adviser can provide lists of dealers located in and serving Illinois. This list includes the kinds of equipment each dealer sells, but it will not supply information about the characteristics of those systems.

If you contact a number of dealers to discuss your individual needs in relation to the type of equipment they sell, you will be in a better position to determine what equipment to purchase.

Subsurface Irrigation

Subirrigation can offer the advantages of good drainage and irrigation using the same system. During wet periods, the system provides drainage to remove excess water. For irrigation, water is forced back into the drains and then into the soil.

This method is most suitable for land where the slope is less than 2 percent, with either a relatively high water table or an impermeable layer at 3 to 10 feet below the surface. The impermeable layer ensures that applied water will remain where needed and that a minimum quantity of water will be sufficient to raise the water table.

The free water table should be maintained at 20 to 30 inches below the surface. This level is controlled and maintained at the head control stands, and water is pumped accordingly. In the event of a heavy rainfall, pumps must be turned off quickly and the drains opened. As a general rule, to irrigate during the growing season, you must deliver a minimum of 5 gallons per minute per acre.

The soil should be permeable enough to allow rapid water movement so that plants are well supplied in peak consumption periods. Tile spacing is a major factor in the cost of the total system and is perhaps the most important single variable in its design and effectiveness. Where subirrigation is suitable, the optimum system will have closer drain spacings than a traditional drainage system.

Irrigation for Double-Cropping

Proper irrigation can eliminate the most serious problem in double-cropping: inadequate water to get the second crop off to a good start. No part of Illinois has better than a 30 percent chance of getting an inch or more of rain during any week in July and most weeks in August. With irrigation equipment available, double-crop irrigation should be a high priority. If you are considering irrigating, evaluate the possibility

of double-cropping in making your decision. Soybeans planted at Urbana on July 6 following a wheat harvest have yielded as much as 38 bushels per acre with irrigation. In Mason County, soybeans planted the first week in July have yielded as much as 30 bushels per acre with irrigation.

While it may be difficult to justify investing in an irrigation system for double-cropping soybeans alone, the potential benefits from irrigating other crops may make the investment worthwhile. Some farmers report that double-cropping is a top priority in their irrigation programs.

Fertigation

The method of irrigation most common in Illinois, the overhead sprinkler, is the one best adapted to applying fertilizer along with water. Fertigation permits nutrients to be applied to the crop as they are needed. Several applications can be made during the growing season with little or no additional application cost. Nitrogen can be applied in periods when the crop has a heavy demand for both nitrogen and water. Corn uses nitrogen and water most rapidly during the 3 weeks before tasseling. About 60 percent of the nitrogen needs of corn must be met by silking time. Generally, nearly all the nitrogen for the crop should be applied by the time it is pollinating, even though some uptake occurs after this time. Fertilization through irrigation can be a convenient and timely method of supplying part of the plant's nutrient needs.

In Illinois, fertigation appears to be best adapted to sandy areas where irrigation is likely to be needed even in the wettest years. On finer-textured soils with high water-holding capacity, nitrogen might be needed even though water is adequate. Neither irrigating just to supply nitrogen nor allowing the crop to suffer for lack of nitrogen is an attractive alternative. Even on sandy soils, only part of the nitrogen should be applied with irrigation water; preplant and sidedress applications should provide the rest of it.

Other problems associated with fertigation can be only mentioned here. These include (1) possible lack of uniformity in application; (2) loss of ammonium nitrogen by volatilization in sprinkling; (3) loss of nitrogen and resultant groundwater contamination by leaching if overirrigation occurs; (4) corrosion of equipment; and (5) incompatibility and low solubility of some fertilizer materials.

Cost and Return

The annual cost of irrigating field corn with a center-pivot system in Mason County was estimated in 1987 to vary from $95 to $140 per acre. The lower figure is for a leased low-pressure system with a 50-horsepower electric motor driving the pump. The higher figure is for a purchased high-pressure system with a 130-horsepower diesel engine. Additional costs associated with obtaining a yield large enough to offset the cost of irrigation were estimated to be about $30 per acre per year, for a total irrigation cost of $125 to $170 per acre per year. The total investment for the purchased high-pressure irrigation system, including pivot, pump and gear head, diesel engine, and a 100-foot well, amounted to $450 per acre. If the low-pressure system were purchased, the total investment for the system, including pivot, pump, electric motor, and a 100-foot well, would be $400.

Irrigation purchases should be based on sound economics. The natural soil-water storage capacity for some soils in Illinois is too good to warrant supplemental irrigation. Based on the assumed fixed and variable costs of about $110 per acre per year, it would require an annual yield differential of about 50 bushels of corn ($2.20 a bushel) or 18 bushels of soybeans ($6 a bushel) to break even (Table 14.01). For irrigation to pay off, these yield differentials would have to be met on the average over the 10- to 15-year life of the irrigation system. Some of the deep, fine-textured soils in Illinois simply would not regularly support these yield increases.

Irrigation Scheduling

Experienced irrigators have developed their own procedures for scheduling applications, whereas beginners may have to determine timing and rates of application before they feel prepared to do so. Irrigators generally follow one of two basic scheduling methods, each of which has many variations.

The first method involves measuring soil water and plant stress by (1) taking soil samples at various

Table 14.01. Break-Even Yield Increase Needed to Cover Fixed and Variable Irrigation Costs

Corn price ($/bu)	Yield increase (bu)	Soybean price ($/bu)	Yield increase (bu)
1.50	67	4.75	21
1.70	59	5.00	20
1.90	53	5.25	19
2.10	48	5.50	18
2.30	43	5.75	17
2.50	40	6.00	17
2.70	37	6.25	16
2.90	34	6.50	15

depths with a soil probe, auger, or shovel and then measuring or estimating the amount of water available to the plant roots; or (2) inserting instruments such as tensiometers or electrical resistance blocks into the soil to desired depths and then taking readings at intervals; or (3) measuring or observing some plant characteristics and then relating them to water stress.

Although in theory the crop can utilize 100 percent of the water that is available, the last portion of that water is not actually as available as the first water that the crop takes from the soil. Much like a half-wrung-out sponge, the remaining water in the soil following 50 percent depletion is more difficult to remove than the first half of the plant-available water.

The 50 percent depletion figure is often used to schedule irrigation. For example, if a soil holds 3 inches of plant-available water in the root zone, then we could allow 1½ inches to be used by the crop before replenishing the soil's water with irrigation.

Soil Samples

Estimating when the 1½ inches is used, or when 50 percent depletion occurs, can be done by a number of methods. One of the simplest is to estimate the amount of depletion by the "feel" method, which involves taking a sample from various depths in the active root zone with a spade, soil auger, or soil probe. It is important to dig a shallow hole to see how the soil looks at 6 to 12 inches early in the irrigation season. As the rooting depth extends to 3 feet, it may be wise to inspect a soil sample from the 9- to 18-inch level and another from the 24- to 30-inch level. Observing only the surface can be misleading on sandy soils because the top portion dries fairly quickly in the summer. To use this method of sampling, follow the guidelines shown in Table 14.02 to identify the depletion range you are in.

Tensiometers

Tensiometers are most suitable for sandy or loamy soils because the changes in soil-water content can be adequately described by the range of soil moisture tension in which they operate. As plant roots dry the soil, soil moisture tension increases and water is pulled from the tensiometer into the surrounding soil, thereby increasing the reading on the vacuum gauge. After irrigation or rainfall, water replenishes the dry soil and soil moisture tension decreases. The vacuum developed in the tensiometer pulls water back through the porous ceramic tip, and the dial gauge reading decreases. By responding to both wetting and drying, a tensiometer can yield information on the effect of crop transpiration or water additions to soil-water status.

A tensiometer must be installed carefully to ensure meaningful readings. Improper use may be worse than not using a tensiometer, because false readings can result in poorly timed irrigation. Before use, each tensiometer assembly must be soaked in water overnight; then the bubbles and dissolved gases must be removed from the water within the tube and ceramic cup. This procedure can be done by using boiled water and a small suction pump available from tensiometer manufacturers.

Table 14.02. Behavior of Soil at Selected Soil-Water Depletion Amounts

Available water remaining in the soil	Soil type: Sands	Soil type: Loamy sand/sandy loam
Soil saturated, wetter than field capacity	Free water appears when soil ball is squeezed	Free water appears when soil ball is squeezed
100% available (field capacity)	When soil ball is squeezed, wet outline on hand but no free water	When soil ball is squeezed, wet outline on hand but no free water
75 to 100%	Sticks together slightly	Forms a ball that breaks easily
50 to 75%	Appears dry; will not form a ball	Appears dry; will not form a ball
Less than 50%	Flows freely as single grains	Flows freely as grains with some small aggregates

The tensiometer should be installed by creating a hole with a soil probe to within 3 to 4 inches of the desired depth, then pounding a rod with a rounded end to the final depth. The rod tip should be shaped like the tensiometer tip to ensure a good, porous cup-to-soil contact. Placement of tensiometers should be made according to two principles: (1) the tensiometer should be readily accessible if it is to be used; and (2) field placement of tensiometers should be made to stagger the readings throughout the irrigation cycle.

Tensiometers are available in lengths ranging from 6 inches to 4 feet. The length required depends on the crop grown, with lengths chosen to gain accurate information in the active root zone. For shallow-rooted vegetable crops, a single tensiometer per station, at a 6- to 9-inch depth, may be sufficient. Multiple-depth stations for corn or soybeans will allow you to track the depletion and recharge of soil water at several depths throughout the season. Because the active root zone shifts as the plant matures, water extraction patterns change as well. If you want to go with a single depth station, refer to Table 14.03 for the proper depths of placement.

Tensiometers may require servicing if soil moisture tension increases to more than 80 centibars. At this tension, air enters the porous cup and the vacuum is broken. Tensiometers that have failed in this manner can be put back into service by filling them with deaerated water. Servicing can be done without removing the tensiometer from the soil. If proper irrigation levels are maintained, the soil moisture tension should not rise to levels sufficient to break the vacuum.

Moisture Blocks

Moisture blocks (sometimes referred to as electrical resistance blocks or gypsum blocks) are small blocks of gypsum with two embedded electrodes. The block operates on the principle that the electrical resistance of the gypsum is affected by water content.

When saturated, the gypsum block has low electrical resistance. As it dries, the electrical resistance increases. The moisture blocks are placed in the soil and electrical leads coming from the embedded electrodes are allowed to protrude from the soil surface. These leads are connected to a portable instrument that includes an electrical resistance meter and a voltage source.

When a reading is desired, a voltage is applied and the resulting reading is recorded. The reading is converted to a soil-water content by using a predetermined calibration curve relating resistance to water content. Soil moisture blocks work well in fine- and medium-textured soils and are not recommended for sandy soils. The increase in fine-textured soil irrigation in Illinois, particularly for seed corn, may prompt an increase in the use of moisture blocks. As with tensiometers, a good soil contact is absolutely necessary for meaningful readings. Soil water must be able to move in and out of the blocks as if the blocks were part of the soil. Any gap between the block and the surrounding soil will prevent this movement.

Another method of scheduling, frequently called the "checkbook method," involves keeping a balance of the amount of soil water by measuring the amount of rainfall and then measuring or estimating the amount of water lost from crop use and evaporation. When the water drops to a certain level, the field is irrigated. Computer techniques are also available for estimating water loss, computing the water balance, and predicting when irrigation is necessary.

Table 14.03. Tensiometer Placement Depth for Selected Crops

	Depth (in.)	Depth (cm)
Soybeans	18	46
Corn	12	30
Snap beans	9	23
Cucumbers	9	23

Management Requirements

Irrigation will provide maximum benefit only when it is integrated into a high-level management program. Good seed or plant starts of proper genetic origin planted at the proper time and at an appropriate population, accompanied by optimum fertilization, good pest control, and other recommended cultural practices, are necessary to ensure the highest benefit from irrigation.

Farmers who invest in irrigation may be disappointed if they do not manage to irrigate properly. Systems are so often overextended that they cannot maintain adequate soil moisture when the crop requires it. For example, a system may be designed to apply 2 inches of water to 100 acres once a week. In two or more successive weeks, soil moisture may be limiting, with potential evapotranspiration equaling 2 inches per week. If the system is used on one 100-acre field one week and another field the next week, neither field may receive much benefit. This is especially true if water stress comes at a critical time, such as during pollination of corn or soybean seed development. Inadequate production of marketable products may result.

Currently I suggest that irrigators follow the cultural practices that they would use for the most

profitable yield in a year of ideal rainfall. In many parts of the state, 1975, 1981, and 1982 were such years. If a farmer's yield is not already appreciably above the county average for that particular soil type, he or she needs to improve management of other cultural factors before investing in an irrigation system.

The availability of irrigation on the farm permits the use of optimum production practices every year. If rains were to come as needed, the investment in irrigation equipment would be unnecessary that year, but no operating costs would be involved. When rainfall is inadequate, however, the yield potential can still be realized with irrigation.

Author

F. William Simmons
Department of Crop Sciences

Chapter 15. 1999 Weed Control for Corn, Soybeans, and Sorghum

This guide is based on the results of research conducted by the personnel of the University of Illinois Agricultural Experiment Station, other experiment stations, and the U.S. Department of Agriculture (USDA). The soils, crops, and weed problems of Illinois have been given primary consideration.

The user should have an understanding of cultural and mechanical weed control. As these practices change little from year to year, this publication focuses on making practical, economical, and environmentally sound decisions regarding herbicide use.

Most of the suggestions in this guide are intended primarily for ground applications. For aerial applications, such factors as carrier volume and adjuvant selection may differ.

Precautions

The benefits of chemical weed control must be weighed against the potential risks to crops, people, and the environment. Discriminate use should minimize exposure of humans and livestock, as well as desirable plants. Risks can be reduced by observing current label precautions.

Current Label

Precautions and directions for use may change. Herbicides classified as restricted-use pesticides (RUP) must be applied only by certified applicators (Table 15.01). Use of these herbicides may be restricted because they are toxic or pose environmental hazards. The degree of toxicity is indicated by the signal word on the label.

Signal Word

Heed the accompanying precautions. The signal word for herbicides discussed in this guide is given in Table 15.01. "Danger—Poison" and "Danger" indicate high toxicity hazards, whereas "Warning" indicates moderate toxicity. Always use personal protective equipment (PPE) as specified on the herbicide label for handling and application. Keep persons or animals not directly involved in the operation out of the area. Observe reentry intervals (REI) as specified on the label. "Agricultural Use Requirement" on the label may require posting of the treated area. Use special drift precautions near residential areas.

Environmental Hazards

Groundwater advisories (Table 15.01) must be observed, especially on sandy soils with a high water table. The threat of toxicity to fish and wildlife is indicated under "Environmental Hazards" on the herbicide label. Hazards to endangered species may be indicated.

Proper Herbicide Use

Apply only to approved crops at the proper rate and time. Illegal residues can result from overapplication or improper timing. Observe the recommended harvesting or grazing intervals after treatment.

Proper Equipment Use

Make sure that spray tanks are clean and free of other pesticide residues. Many herbicide labels provide cleaning suggestions, which are particularly important

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The information in this chapter is provided for educational purposes only. Product trade names have been used for clarity, but reference to trade names does not imply endorsement by the University of Illinois; discrimination is not intended against any product. The reader is urged to exercise caution in making purchases or evaluating product information.

Label registrations can change at any time. Thus the recommendations in this chapter may become invalid. The user must read carefully the entire, most recent label and follow all directions and restrictions. Purchase only enough pesticide for the current growing season.

Table 15.01. Herbicide and Herbicide Premix Names and Restrictions

Trade name(s)	Common (generic) name(s)	Restricted-use pesticide[a]	Groundwater advisory[b]	Signal word[c]	Crop
AAtrex, Atrazine	Atrazine	Yes	Yes	Caution	C
Accent	Nicosulfuron	—	—	Caution	C
Accent Gold	Nicosulfuron + rimsulfuron + flumetsulam + clopyralid	—	Yes	**Danger**	
Aim	Carfentrazone-ethyl	—	—	Caution	C
Assure II/Matador	Quizalofop	—	—	**Danger**	S
Authority First	Sulfentrazone	—	Yes	Caution	S
Axiom	FOE-5043 + metribuzin	—	Yes	Caution	S
Balance	Isoxaflutole	Yes	Yes	Caution	C&S
Banvel/Clarity	Dicamba	—	—	Warning/Caution	C
Basagran	Bentazon	—	Yes	Caution	C&S
Basis	Rimsulfuron + thifensulfuron	—	—	Caution	C
Basis Gold	Rimsulfuron + nicosulfuron + atrazine	Yes	Yes	Caution	C
Beacon	Primisulfuron	—	—	Caution	C
Bicep II Magnum	S-metolachlor + atrazine + safener	Yes	Yes	Caution	C
Bicep Lite II Magnum	S-metolachlor + atrazine + safener	Yes	Yes	Caution	C
Bladex, Cy-Pro	Cyanazine	Yes	Yes	Warning	C
Blazer, Status	Acifluorfen	—	Yes	**Danger**	S
Broadstrike + Dual	Flumetsulam + metolachlor	—	Yes	Warning	C&S
Broadstrike + Treflan	Flumetsulam + trifluralin	—	Yes	**Danger**	S
Buctril, Moxy	Bromoxynil	—	—	Warning	C
Buctril + Atrazine	Bromoxynil + atrazine	Yes	Yes	Caution	C
Bullet	Alachlor + atrazine	Yes	Yes	Caution	C
Butyrac 200/Butoxone	2,4-DB	—	—	**Danger**	S
Canopy	Metribuzin + chlorimuron	—	Yes	Caution	S
Canopy XL	Sulfentrazone + chlorimuron	—	Yes	Caution	S
Classic/Skirmish	Chlorimuron	—	—	Caution	S
Cobra	Lactofen	—	—	**Danger**	S
Command 3ME	Clomazone	—	—	Caution	S
Contour	Imazethapyr + atrazine	Yes	Yes	Caution	C
Detail	Imazaquin + dimethenamid	—	Yes	**Danger**	S
DoublePlay	Acetochlor + EPTC + safener	Yes	Yes	Warning	C
Dual II Magnum	S-metolachlor + safener	—	Yes	Caution	C&S
Eradicane	EPTC + safener	—	—	Caution	S
Exceed	Primisulfuron + prosulfuron	—	Yes	Caution	C
Extrazine II, Cy-Pro AT	Cyanazine + atrazine	Yes	Yes	Warning	C
Fieldmaster	Glyphosate + acetochlor + atrazine + safener	Yes	Yes	Caution	C
FirstRate	Cloransulam	—	Yes	Caution	S
Flexstar/Reflex	Fomesafen	—	—	Warning/**Danger**	S
Frontier	Dimethenamid	—	Yes	Warning	C&S
FulTime	Acetochlor + atrazine + safener	Yes	Yes	Caution	C
Fusilade DX	Fluazifop	—	—	Caution	S
Fusion	Fluazifop + fenoxaprop	—	—	Caution	S
Galaxy, Storm	Bentazon + acifluorfen	—	Yes	**Danger**	S
Gramoxone Extra	Paraquat	Yes	—	**Danger—Poison**	C&S
Guardsman/LeadOff	Dimethenamid + atrazine	Yes	Yes	Caution	C
Harness	Acetochlor + safener	Yes	Yes	Warning	C
Harness Xtra	Acetochlor + atrazine + safener	Yes	Yes	Caution	C

Table 15.01. Herbicide and Herbicide Premix Names and Restrictions (cont.)

Trade name(s)	Common (generic) name(s)	Restricted-use pesticide[a]	Groundwater advisory[b]	Signal word[c]	Crop[d]
Hornet	Flumetsulam + clopyralid	—	Yes	**Danger**	C
Laddok S-12	Bentazon + atrazine	Yes	Yes	**Danger**	C
Lasso/Micro-Tech	Alachlor	Yes	Yes	**Danger**/Caution	C&S
Liberty	Glufosinate	—	—	Warning	C&S
Liberty ATZ	Glufosinate + atrazine	Yes	Yes	Caution	C
Lightning	Imazethapyr + imazapyr	—	Yes	Warning	C
Lorox	Linuron	—	—	Caution	S
Marksman	Dicamba + atrazine	Yes	Yes	Caution	C
Many trade names	2,4-D amine	—	—	**Danger**	C
Many trade names	2,4-D ester	—	—	Caution	C
NorthStar	Primisulfuron + dicamba	—	Yes	Caution	C
OpTill	Prosulfuron	—	Yes	Caution	C
Permit	Halosulfuron	—	—	Caution	C
Pinnacle	Thifensulfuron	—	—	Caution	S
Poast Plus, Prestige	Sethoxydim	—	—	Caution	S
Princep, Simazine	Simazine	—	Yes	Caution	C
Prowl, Pentagon	Pendimethalin	—	—	Caution	C&S
Pursuit	Imazethapyr	—	—	Caution	C&S
Pursuit Plus	Pendimethalin + imazethapyr	—	—	Caution	C&S
Python	Flumetsulam	—	Yes	Caution	C&S
Raptor	Imazamox	—	—	Caution	S
Resolve	Imazethapyr + dicamba	—	—	Warning	C
Resource	Flumiclorac	—	—	Warning	C&S
Roundup Ultra	Glyphosate, isopropylamine	—	—	Caution	C&S
Scepter 70DF	Imazaquin	—	—	Caution	S
Scorpion III	Flumetsulam + clopyralid + 2,4-D	—	Yes	**Danger**	C
Select	Clethodim	—	—	Warning	S
Sencor, Lexone	Metribuzin	—	Yes	Caution	S&C
Shotgun	Atrazine + 2,4-D	Yes	Yes	**Danger**	C
Sonalan	Ethalfluralin	—	—	Caution	S
Spirit	Primisulfuron + prosulfuron	—	Yes	Warning	C
Squadron	Imazaquin + pendimethalin	—	—	**Danger**	S
Steel	Pendimethalin + imazethapyr + imazaquin	—	—	Warning	S
Stellar	Lactofen + flumiclorac	—	—	**Danger**	S
Stinger	Clopyralid	—	Yes	Caution	C
Surpass/TopNotch	Acetochlor + safener	Yes	Yes	Warning/Caution	C
Surpass 100	Acetochlor + atrazine + safener	Yes	Yes	**Danger**	C
Sutan+	Butylate + safener	—	—	Caution	C
Synchrony STS	Chlorimuron + thifensulfuron	—	—	Caution	S
Touchdown 5	Glyphosate, trimesium	—	—	Caution	C&S
Tough	Pyridate	—	—	Warning	C
Treflan, Tri-4	Trifluralin	—	—	Caution	S
Tri-Scept	Imazaquin + trifluralin	—	—	Warning	S
Turbo	Metribuzin + metolachlor	—	Yes	Caution	S

[a]To be applied by licensed applicator.
[b]Special precautions in sandy soils.
[c]Signal word = toxicity signal; indicates need for extra precautions. The signal words **"Danger"** and "Warning" often indicate pesticides that can irritate skin and eyes, necessitating protective clothing, gloves, and goggles or faceshield.
[d]C = corn; S = soybeans.

when spraying different crops with the same sprayer and especially when using postemergence herbicides. Correctly calibrate and adjust the sprayer before adding the herbicide to the tank.

Proper Drift Precautions

Spray only on relatively calm days when the wind is light. Make sure the wind is not moving toward areas of human activity, susceptible crops, or ornamental plants. Nearby residential areas and fields of edible horticultural crops deserve special attention. *Use special precautions with 2,4-D, Banvel or Clarity, Command 3ME, Gramoxone Extra, Hornet, Marksman, Resolve, Roundup Ultra, Scorpion III, Shotgun, and Stinger,* as symptoms of injury have occurred far from the application site.

Precautions to Protect the Crop

Avoid applying a herbicide to crops under stress or predisposed to injury. Crop sensitivity varies with size of the crop and climatic conditions, as well as previous injury from plant diseases, insects, or chemicals.

Proper Recropping Interval

Failure to observe the proper recropping intervals may result in carryover injury to the next crop. Soil texture, organic matter, and pH may affect herbicide persistence. Check Tables 15.02a and 15.02b and current labels for recropping restrictions.

Proper Storage

Promptly return unused herbicides to a safe storage place. Pesticides should be stored in their original, labeled containers in a secure place away from unauthorized people (particularly children) and livestock and their food or feed.

Proper Container Disposal

Liquid containers should be pressure- or triple-rinsed. Properly rinsed containers can be recycled or may be accepted by some sanitary landfills. Haul paper containers to a sanitary landfill or burn them in an approved manner. If possible, use mini-bulk returnable containers.

Cultural and Mechanical Control

Good cultural practices that aid in weed control include adequate seedbed preparation, adequate fertilization, crop rotation, planting on the proper date, using the optimal row width, and seeding at the rate required for optimal stands.

Planting in relatively warm soil can help the crop emerge quickly and compete better with weeds. Good weed control during the first 3 to 5 weeks is extremely important for both corn and soybeans, as they will usually compete quite well with most of the weeds that begin growing later. Narrow rows help the crop compete better with the weeds. However, if herbicides alone cannot give adequate weed control, then keep rows wide enough to allow for cultivation.

If adequate rainfall does not occur after the application of a soil-applied herbicide, use the rotary hoe after weed seeds have germinated but before most weeds have emerged. Operate it at 8 to 12 miles per hour, and weight it enough to stir the soil and kill the tiny weeds. Rotary hoeing also aids crop emergence if the soil is crusted.

Row cultivators also should be used while weeds are small. Throwing soil into the row can help smother small weeds. Proper adjustment of equipment (speed, depth, and angle) is essential for minimizing crop injury and pruning crop roots. Cultivation may not be needed where herbicides are adequately controlling weeds, unless the soil is crusted or needs aeration.

Herbicide Incorporation

DoublePlay, Eradicane, Sonalan, Sutan+, trifluralin, and Tri-Scept are incorporated to minimize surface loss. Other soil-applied herbicides may be incorporated to minimize dependence on timely rainfall or to improve control of certain weed species.

Incorporation should place the herbicide uniformly throughout the top 1 to 2 inches of soil for the best control of most weeds. Slightly deeper placement may improve the control of certain weeds under relatively dry conditions but may dilute the herbicide and reduce its effectiveness. Incorporation tools usually distribute most of the herbicide into the soil to about one-half the depth of operation. Thus, for most herbicides, the suggested depth of operation is 3 to 4 inches for most tillage tools.

Thorough incorporation often requires two passes, but the second pass may be delayed if the first pass adequately reduces surface loss of the herbicide. The second pass should be at an angle to the first pass and no deeper. Single-pass incorporation may be adequate, especially if rotary hoeing, cultivation, or subsequent herbicide treatment maintains adequate weed control.

Accurate application and uniform distribution help minimize crop injury and carryover problems. Uniform distribution depends on the type of equipment used, the depth and speed of operation, the texture of the soil, and the amount of soil moisture.

Table 15.02a. Corn-Sorghum Herbicide Recropping Restrictions, Months

Herbicide[a]	Comments	Field corn	Sorghum	Wheat	Oats	Rye	Alfalfa	Clover	Soybeans
Acetochlor and its premixes									
DoublePlay	w/EPTC	AT	NY	4	2Y	2Y	2Y	2Y	NY
FulTime	w/atrazine	AT	NY	15	2Y	2Y	2Y	2Y	NY[b]
Harness	acetochlor	AT	NY	4	2Y	2Y	2Y	2Y	NY
Harness Xtra 5.6L	w/atrazine	AT	NY	15	2Y	2Y	2Y	2Y	NY
Surpass/TopNotch	acetochlor	AT	NY	4	2Y	2Y	2Y	2Y	NY
Surpass 100	w/atrazine	AT	NY	15	2Y	2Y	2Y	2Y	NY[b]
Atrazine and its premixes; simazine									
AAtrex, Atrazine	pH < 7.2	AT	AT	NY	2Y	NY	2Y	2Y	NY[b]
Bicep II Magnum	w/metolachlor	AT	AT[c]	NY	2Y	NY	2Y	2Y	NY[b]
Bicep Lite II Magnum	w/metolachlor	AT	AT[c]	NY	2Y	NY	2Y	2Y	NY[b]
Buctril + Atrazine	w/bromoxynil	AT	AT	NY	2Y	NY	2Y	2Y	NY
Bullet	w/alachlor	AT	AT[c]	NY	2Y	NY	2Y	2Y	NY[b]
Extrazine	w/cyanazine	AT	1	15	15	15	18	18	NY[b]
Guardsman/LeadOff	w/dimethenamid	AT	AT[c]	NY	2Y	NY	2Y	2Y	NY[b]
Laddok S-12	w/bentazon	AT	AT	15	15	15	18	18	NY
Liberty ATZ	w/glufosinate	AT	AT	NY[b]	2Y	NY[b]	NY[b]	NY[b]	NY[b]
Marksman	w/dicamba	AT	AT	10	10	10	2Y	2Y	NY[b]
Princep	simazine	AT	NY	NY	2Y	NY	2Y	2Y	NY
Flumetsulam and its premixes; clopyralid									
Broadstrike + Dual	w/metolachlor	AT	12	4.5	4.5	4.5	4	26[Fba]	AT
Hornet	w/clopyralid	AT	12	4	4	4	10.5	26[Fba]	10.5[e]
Python	flumetsulam	AT	12	4	4	4	4	26[Fba]	AT
Scorpion III	w/clopyralid + 2,4-D	AT	12	4	4	4	10.5	26[Fba]	10.5[e]
Stinger	clopyralid	AT	10.5	AT	AT	AT	10.5	18	10.5[e]
Imazethapyr and its premixes									
Contour	w/atrazine	8.5[f]	18	9.5	18	9.5	18	40[Fba]	9.5
Lightning	w/imazapyr	8.5[f]	18	4	18	4	9.5	40[Fba]	9.5
Pursuit	imazethapyr	8.5[f]	18	4	18	4	4	40[Fba]	AT
Pursuit Plus	w/pendimethalin	8.5	18	4	18	9.5	9.5	40[Fba]	AT
Resolve	w/dicamba	8.5[f]	18	4	18	4	9.5	40[Fba]	9.5
Sulfonylureas and their premixes									
Accent	nicosulfuron	AT	10[d]	4	8	4	10	10	0.5
Accent Gold	(A) + (R) + Hornet	AT	12	4	8	4	10.5	26[Fba]	10.5[e]
Basis	thifensulfuron + rimsulfuron	AT	10	4	8	18	10	18	0.5
Basis Gold	nicosulfuron + rimsulfuron + atrazine	AT	10	10	18	10	18	18	10[b]
Beacon	primisulfuron	0.5	8	3	8	3	8	18	8
Celebrity B & G	dicamba + nicosulfuron	AT	10[d]	4	8	4	10	10	1
Exceed, Spirit	primisulfuron + prosulfuron	1	10	3	3	3	18[g]	18[g]	10–18[h]
NorthStar	primisulfuron+dicamba	0.5	8	3	8	3	8	18	8
Permit	halosulfuron	1	2	2	2	2	9	9	9

[Fba] = field bioassay needed (see label), NY = next year, 2Y = second year, AT = anytime.
[a]Other corn herbicides have no significant recropping restriction; but Banvel, Clarity, Eradicane, and 2,4-D have replanting limits for soybeans.
[b]2Y (second year) if applied after June 10 with high atrazine or July 1 with Basis Gold.
[c]Concep or Screen seed protectant needed.
[d]18 months if pH ≥ 7.5.
[e]18 months if < 15 inches of rainfall received and if soil has < 2% organic matter.
[f]IMI-corn hybrids may be replanted anytime.
[g]Exceed or Spirit: pH < 7.8; applied before July 1; rainfall > 12 inches within 5 months and > 1 inch within 4 weeks of application.
[h]I-70 to I-80: Spirit 10 months, Exceed 18 months or 10 months if STS soybeans. Above I-80: Exceed or Spirit 18 months.

Table 15.02b. Soybean Herbicide Recropping Restrictions, Months

Herbicide	Comments	Field corn	Sorghum	Wheat	Oats	Rye	Alfalfa	Clover	Soybeans
Chlorimuron and some of its premixes									
Canopy[a]	w/metribuzin	10	12	4	30	30	10	12	AT
Classic/Skirmish	high chlorimuron	9[b]	9[b]	3	3	3	12[b]	12[b]	AT
Synchrony STS	w/thifensulfuron	9[b]	9[b]	3	3	3	12[b]	12[b]	AT
Flumetsulam and its premixes; cloransulam									
Broadstrike + Dual	w/metolachlor	AT	12	4.5	4.5	4.5	4	26[Fba]	AT
Broadstrike + Treflan	w/trifluralin	8	12	4	12	4	4	26[Fba]	AT
FirstRate	cloransulam	9	9	3	30[Fba]	30[Fba]	9	30[Fba]	AT
Python	flumetsulam	AT	12	4	4	4	4	26[Fba]	AT
Imazaquin and its premixes (full rate = Detail, Squadron, Tri-Scept; Region 3 = north of Peoria)									
Detail—Region 2[c]	w/dimethenamid	9.5[d,e]	11[e]	4[e]	11[e]	18	18	18	AT
Scepter—Region 2[c]	imazaquin	9.5[d,e]	11[e]	3[e]	11[e]	18	18	18	AT
Scepter—Region 3[c]	0.5 rate, post	NY[d]	11	Fall[e]	NY[e]	18	18	18	AT
Scepter—Region 3[c]	imazaquin	18	11	18	18	18	18	18	AT
Squadron—Region 2[c]	w/pendimethalin	9.5[d,e]	11[e]	4[e]	11[e]	18	18	18	AT
Tri-Scept—Region 2[c]	w/trifluralin	9.5[d,e]	11[e]	4[e]	11[e]	18	18	18	AT
Imazethapyr and its premixes (full rate = Pursuit, Pursuit Plus; Steel = Pursuit Plus + 0.5X Scepter)									
Pursuit	imazethapyr	8.5[f]	18	4	18	4	4	40	AT
Pursuit Plus	w/pendimethalin	8.5	18	4	18	9.5	9.5	40	AT
Steel—Region 2[c]	w/pendimethalin + imazaquin	9.5[d,e]	18	4[e]	18	40	18	40	AT
Sulfentrazone alone or plus chlorimuron									
Authority First	sulfentrazone	10	10	4	30	4	12	18	AT
Canopy XL[a]	w/chlorimuron[a]	10	10	4	30	4	12	18	AT
Other active ingredients									
Command 3ME	clomazone	9	9	12	16[g]	16[g]	16[g]	16[g]	AT
Flexstar, Reflex	fomesafen	10	18	4	4	4	10	18	AT
Raptor	imazamox	9	9	3	9	4	9	18	AT
Sencor, Lexone	metribuzin	4	12	4	12	12	4	12	4
Turbo	metribuzin + metolachlor	8	12	4.5	12	12	12	12	8

[Fba] = field bioassay needed (see label), NY = next year, 2Y = second year, AT = anytime.
[a]Midwest states' rate, soil pH < 6.8.
[b]Extend 2 months if applied after August 1.
[c]See label for exact area and Region 3 (northern Illinois) full-use rate.
[d]10- to 15-inch annual rainfall is required, or use IMI-corn hybrids.
[e]15 months if Scepter/Scepter O.T. sequence, but 9.5 months or NY for IMI-corn hybrids.
[f]IMI-designated corn hybrids may be planted anytime.
[g]Cover crops may be planted anytime, but stand reductions may occur. Do not graze or harvest for forage for at least 9 months.

Field cultivators, tandem disks, and disk-chisels or other combination tools are sometimes used for incorporation. More uniform herbicide distribution is provided by two passes than one, whether with a field cultivator or tandem disk.

Field Cultivators

Field cultivators used for herbicide incorporation need at least three rows of shanks equipped with sweeps (not points) each with an effective working space of 7 inches or less. Sweeps for C-shank cultivators should be at least as wide as the effective shank spacing. Set the equipment to cut in a level position at 3 to 4 inches deep, and operate at a minimum of 5 miles per hour.

Tandem Disks

Tandem disks used for herbicide incorporation should have disk blade diameters of 20 inches or less and blade spacings of 7 to 9 inches. *Do not use larger disks for incorporating herbicides.* Set the disk to cut 3 to 4 inches deep and operate at 4 to 6 miles per hour or a speed sufficient to move soil the full width of the blade spacing. Slower speeds or lack of a leveling device can result in herbicide streaking.

Combination Tools

Several tillage tools combine disk gangs, field cultivator shanks, and leveling devices. Many combination tools can handle large amounts of surface residue without clogging and yet leave adequate crop residue on the soil surface for erosion control. Results indicate that these combination tools may provide more uniform one-pass incorporation than a disk or field cultivator, but one pass with them is generally no better than two passes with the disk or field cultivator.

Chemical Weed Control

Plan your weed control program to fit your soils, tillage program, crops, weed problems, and farming operations. Good herbicide performance depends on the weather and on wise selection and application. Your decisions about herbicide use should be based on the nature and seriousness of your weed problems. The herbicide susceptibility of common weed species is indicated in several tables in this guide.

Corn or soybeans are occasionally injured by herbicides applied to these crops. To minimize crop injury, apply the herbicide uniformly, at the stage of crop growth specified on the label and at the correct rate (see the section on "Herbicide Rates"). Crop tolerance ratings for various herbicides are also given in the tables in this chapter. Unfavorable conditions such as cool, wet weather, delayed crop emergence, deep planting, seedling diseases, soil in poor physical condition, and poor-quality seed may contribute to crop stress and herbicide injury. Hybrids and varieties vary also in their tolerance to herbicides and environmental stress factors. Once injured by a herbicide, plants may be more prone to disease.

Crop planting options for next season also must be considered when selecting a herbicide program. Corn and soybean herbicides may have restrictive recropping intervals for some agronomic and many vegetable crops. Tables 15.02a and 15.02b cover recropping intervals for the major agronomic crops grown in Illinois, but always check the label. Recropping intervals may be extended for previous, subsequent, or late-summer herbicide applications, as well as droughty weather or soil pH. Command or Scepter (in northern Illinois) can restrict planting wheat after soybeans, whereas atrazine restricts planting wheat after corn. For soybeans, the persistent corn herbicides of concern are atrazine, clopyralid, and prosulfuron. STS soybeans may help reduce carryover problem with prosulfuron. Special concerns are rate and date of application, as well as rainfall amount and soil pH. When corn follows soybeans, the major concerns are imazaquin and chlorimuron, but imidazolinone-resistant (IR) hybrids can minimize this concern (see the label). Be sure that the application of persistent herbicides is uniform and properly timed to minimize injury to wheat or corn. Refer to the herbicide label for information about cropping sequence and appropriate recropping intervals.

For some herbicides, different formulations and concentrations are available under the same trade name. *No endorsement of any trade name is implied, nor is discrimination against similar products intended.*

Weed Resistance to Herbicides

One of the disadvantages of chemical weed control is that weeds can become resistant to herbicides. Herbicide resistance is not presently a major problem in Illinois, but it could become a problem without proper management. There are triazine-resistant pigweed, lambsquarters, and kochia, as well as acetolactate synthase (ALS)–resistant waterhemp, kochia, and cocklebur in Illinois. The imidazolinone, sulfonylurea, and sulfonamide herbicides all have the same mode of action, inhibiting the ALS enzyme. In Illinois, ALS-inhibiting herbicides are widely used in soybeans, and their use is increasing in corn. This trend, if not managed properly, has the potential to increase the weed resistance problem in Illinois.

Certain management strategies can help deter the development of herbicide-resistant weeds:

1. Scout fields regularly to identify resistant weeds. Monitor changes in weed populations to restrict the spread of herbicide-resistant weeds.
2. Rotate herbicides with different modes of action. Do not make more than two consecutive applications of herbicides (whether within the same year or in successive years) with the same mode of action against the same weed. Instead, include other effective management strategies for weed control. This is especially critical when using herbicide-tolerant crops.
3. Use multiple modes of action (tank-mix, premix, or sequential) that will effectively control potentially resistant weeds.
4. Where practical, use rotary hoeing and cultivation to control weed escapes. If necessary, use hand weeding to minimize the spread of herbicide-tolerant weeds.
5. Be aware that resistant weeds can spread from total vegetation control (TVC) programs used along highway, railroad, or utility rights-of-way areas near your farm.

For further information on the causes of herbicide resistance and strategies to minimize it, visit your Extension Center or see the *Illinois Agricultural Pest Management Handbook*, Chapter 19, "Weed Resistance to Herbicides."

Herbicide Combinations

Herbicide combinations (tank, pre-, or sequential mix) can control more weed species, reduce carryover, and reduce crop injury. Some labels allow split applications (the same herbicide applied at different times) or sequential applications (different herbicides applied at different times). Numerous combinations of herbicides are sold as premixes, and some are tank-mixed. Registered premixes (Tables 15.03 and 15.04) and tank mixes are shown in the tables in this chapter. Tank-mixing allows you to adjust the ratio of herbicides to fit local weed and soil conditions, whereas premixes may overcome some of the compatibility problems found with tank-mixing. When using a tank mix, you must follow restrictions for all products used in the combination.

Problems may occur when mixing emulsifiable concentrate (EC) formulations with suspendible herbicides, such as liquid flowable (L) or dry-flowable (DF) formulations. Proper mixing procedure may minimize these problems. The label of most soil-applied herbicides specifies a compatibility test when a liquid fertilizer carrier is used. First, fill tanks at least one-fourth full with carrier (water or liquid fertilizer) and start tank agitation. Next, if needed, add the compatibility agent at the rate indicated by the test or adjuvant label. Add suspendible herbicide formulations as just described and completely suspend (thoroughly mix) before adding emulsifiable concentrates. Mix ECs with equal volumes of water (thoroughly emulsify) before adding them to the tank. Add soluble formulations (those that do not emulsify or disperse) last. Empty and clean spray tanks often enough to prevent accumulation of material on the sides and the bottom of the tank.

Herbicide Rates

Herbicide rates vary according to the time and method of application, the soil conditions, the tillage system used, and the seriousness of the weed infestation. Rates of individual components within a combination are usually lower than rates for the same herbicides used alone.

The rates for soil-applied herbicides often vary with the texture of the soil and the amount of organic matter the soil contains. For sandy soils, the herbicide label may specify reducing the rate or not using any if crop tolerance to the herbicide is marginal. Postemergence rates often vary, depending on the size and species of the weeds.

The rates given in this chapter are, unless otherwise specified, broadcast rates for the amount of formulated product. If you plan to band or direct herbicides, adjust the amount per crop acre according to the percentage of the area actually treated. Herbicides may have formulations with different concentrations of the active ingredient. Be sure to read the label and make necessary adjustments when changing formulations.

Postemergence Herbicide Principles

Postemergence herbicides applied to growing weeds generally have foliar rather than soil action; however, some may have both. The rates and timing of applications are based on weed size and climatic conditions. When weeds are small, they usually can be controlled with lower application rates. Larger weeds often require higher herbicide rates. Herbicide penetration and action are usually greater with warm temperature and high relative humidity. Rainfall occurring too soon after application (0.5 to 6 hours, depending on the herbicide) can reduce weed control.

Translocated herbicides are most effective at lower spray volumes (5 to 20 gallons per acre), whereas contact herbicides require more complete coverage. Foliar coverage increases as water volume and spray pressure are increased. Spray nozzles that produce small droplets also improve coverage. For contact herbicides,

Table 15.03. Corn Herbicide Premixes, or Co-packs, and Equivalents

Herbicide	Components (a.i./gal or lb)	If you apply (per acre) . . .	You have applied (a.i.)	An equivalent rate of
Accent Gold 83.8WG	0.065 lb nicosulfuron 0.065 lb rimsulfuron 0.517 lb clopyralid 0.191 lb flumetsulam	2.9 oz	0.188 oz nicosulfuron 0.188 oz rimsulfuron 1.50 oz clopyralid 0.554 oz flumetsulam	0.25 oz Accent 75DF 0.188 oz rimsulfuron 4.0 fl oz Stinger 3S 0.69 oz Python 80WG
Axiom 68DF	0.544 lb FOE-5043 0.136 lb metribuzin	19 oz	10.34 oz FOE-5043 2.58 oz metribuzin	10.34 oz a.i. FOE-5043 3.45 oz Sencor 75DF
Basis 75DF	0.50 lb rimsulfuron 0.25 lb thifensulfuron	0.33 oz	0.167 oz rimsulfuron 0.083 oz thifensulfuron	0.167 oz a.i. rimsulfuron 0.33 oz Pinnacle 25DF
Basis Gold 89.5DF	0.0134 lb rimsulfuron 0.0134 lb nicosulfuron 0.8678 lb atrazine	14 oz	0.188 oz rimsulfuron 0.188 oz nicosulfuron 12.15 oz atrazine	0.188 oz a.i. rimsulfuron 0.25 oz Accent 75DF 13.5 oz atrazine 90DF
Bicep II 5.9L	3.23 lb metolachlor 2.67 lb atrazine	2.4 qt	1.94 lb metolachlor 1.60 lb atrazine	1.0 qt Dual II 7.8EC 1.6 qt atrazine 4L
Bicep II Magnum 5.5L	2.40 lb S-metolachlor 3.1 lb atrazine	2.1 qt	1.26 lb S-metolachlor 1.63 lb atrazine	0.66 qt Dual II Magnum 7.62EC 1.63 qt atrazine 4L
Bicep Lite Magnum 6L	3.33 lb S-metolachlor 2.67 lb atrazine	1.5 qt	1.25 lb S-metolachlor 1.00 lb atrazine	0.66 qt Dual II Magnum 7.62EC 1.00 qt atrazine 4L
Bicep Lite II 4.9L	3.23 lb metolachlor 1.67 lb atrazine	2.4 qt	1.94 lb metolachlor 1.00 lb atrazine	1 qt Dual II 7.8EC 1 qt atrazine 4L
Broadstrike + Dual 7.67EC	0.20 lb flumetsulam 7.47 lb metolachlor	2.5 pt	1.0 oz flumetsulam 2.33 lb metolachlor	1.25 oz Python 80WG 2.33 pt Dual 8EC
Buctril + Atrazine 3L	1.0 lb bromoxynil 2.0 lb atrazine	2 pt	0.25 lb bromoxynil 0.50 lb atrazine	1 pt Buctril 2EC 1 pt atrazine 4L
Bullet 4ME	2.5 lb alachlor 1.5 lb atrazine	4 qt	2.5 lb alachlor 1.5 lb atrazine	2.5 qt Micro-Tech 4ME 1.5 qt atrazine 4L
Celebrity B & G (co-pack)	B=0.70 lb dicamba G=0.75 lb nicosulfuron	6.0 oz 0.66 oz	4.2 oz dicamba 0.5 oz nicosulfuron	8.4 fl oz Clarity 4S 0.66 oz Accent 74DF
Contour 3.38L[a]	0.38 lb imazethapyr 3.00 lb atrazine	1.33 pt	0.063 lb imazethapyr 0.500 lb atrazine	4 fl oz Pursuit 2SC 1.00 pt atrazine 4L
DoublePlay 7EC	1.4 lb acetochlor 5.6 lb EPTC	5 pt	0.875 lb acetochlor 3.50 lb EPTC	1.1 pt Surpass 6.4EC 4.2 pt Eradicane 6.7EC
Exceed 57WG	0.285 lb primisulfuron 0.285 lb prosulfuron	1 oz	0.285 oz primisulfuron 0.285 oz prosulfuron	0.38 oz Beacon 75WG 0.5 oz Peak 57WG
Extrazine II 4L or Cy-Pro AT 4L	1.0 lb atrazine 3.0 lb cyanazine	1.3 qt	0.33 lb atrazine 0.98 lb cyanazine	0.33 qt atrazine 4L 1.0 qt cyanazine 4L
Extrazine II 90DF or Cy-Pro AT 90DF	0.225 lb atrazine 0.675 lb cyanazine	1.5 lb	0.33 lb atrazine 1.01 lb cyanazine	0.375 lb atrazine 90DF 1.12 lb cyanazine 90DF
Fieldmaster 4.06L	2.0 lb acetochlor 1.5 lb atrazine 0.56 lb glyphosate	4 qt	2.0 lb acetochlor 1.5 lb atrazine 0.56 lb glyphosate	2.3 pt Harness 7EC 3.0 pt atrazine 4L 1.5 pt Roundup 3S

Table 15.03. Corn Herbicide Premixes, or Co-packs, and Equivalents (cont.)

Herbicide	Components (a.i./gal or lb)	If you apply (per acre) . . .	You have applied (a.i.)	An equivalent rate of
FulTime 4CS	2.4 lb acetochlor 1.6 lb atrazine	4 qt	2.4 lb acetochlor 1.6 lb atrazine	3.00 qt TopNotch 3.2CS 1.6 qt atrazine 4L
Guardsman 5L or LeadOff 5L	2.33 lb dimethenamid 2.67 lb atrazine	4.5 pt	1.31 lb dimethenamid 1.50 lb atrazine	28 fl oz Frontier 6EC 3.00 pt atrazine 4L
Harness Xtra 5.6L	3.1 lb acetochlor 2.5 lb atrazine	5.0 pt	1.94 lb acetochlor 1.56 lb atrazine	2.21 pt Harness 7E 3.12 pt atrazine 4L
Harness Xtra 6L	4.3 lb acetochlor 1.7 lb atrazine	5.0 pt	2.15 lb acetochlor 0.85 lb atrazine	2.46 pt Harness 7EC 1.7 pt atrazine 4L
Hornet 85.6WG	0.231 lb flumetsulam 0.625 lb clopyralid	4 oz	0.924 oz flumetsulam 2.50 oz clopyralid	1.16 oz Python 80WG 6.67 fl oz Stinger 3C
Laddok S-12 5L	2.5 lb bentazon 2.5 lb atrazine	1.67 pt	0.52 lb bentazon 0.52 lb atrazine	1.0 pt Basagran 4SC 1.0 pt atrazine 4L
Liberty ATZ 4.3L	3.3 lb atrazine 1.0 lb glufosinate	40 fl oz (2.5 pt)	1.03 lb atrazine 0.312 lb glufosinate	32 fl oz atrazine 4L 24 fl oz Liberty 1.67
Lightning 70DG[a]	0.525 imazethapyr 0.175 imazapyr	1.28 oz	0.672 oz imazethapyr 0.224 oz imazapyr	0.96 oz Pursuit 70DG 0.32 oz imazapyr 70DF
Marksman 3.2L	1.1 lb dicamba 2.1 lb atrazine	3.5 pt	0.48 lb dicamba 0.92 lb atrazine	0.96 pt Banvel 4SC 1.84 pt atrazine 4L
Moxy + Atrazine 3L	1.0 lb bromoxynil 2.0 lb atrazine	2 pt	0.25 lb bromoxynil 0.50 lb atrazine	1 pt Moxy 2EC 1 pt atrazine 4L
NorthStar 43.8WG	0.075 lb primisulfuron 0.363 lb dicamba (Na)	5 oz	0.375 oz primisulfuron 1.815 oz dicamba	0.50 oz Beacon 75WG 3.63 fl oz Banvel 4SC
OpTill 6EC	5 lb dimethenamid 1 lb dicamba	38 fl oz	1.48 lb dimethenamid 0.297 lb dicamba	31.7 fl oz Frontier 6EC 9.5 fl oz Banvel 4SC
Resolve 75SG[a]	0.187 lb imazethapyr 0.563 lb dicamba	5.33 oz	1.00 oz imazethapyr 3.00 oz dicamba	1.42 oz Pursuit 70DG 6 fl oz Banvel 4SC
Scorpion III 84.3WDG	0.093 lb flumetsulam 0.25 lb clopyralid 0.50 lb 2,4-D	4 oz	0.372 oz flumetsulam 1.00 oz clopyralid 2.00 oz 2,4-D	0.46 oz Python 80WG 2.67 fl oz Stinger 3SC 2.00 oz a.e. 2,4-D
Shotgun 3.25L	2.25 lb atrazine 1 lb 2,4-D	2 pt	0.56 lb atrazine 0.25 lb a.e. 2,4-D	1.12 pt atrazine 4L 0.53 pt Esteron 99 3.8EC
Spirit 57WDG	0.428 lb primisulfuron 0.142 lb prosulfuron	1 oz	0.428 oz primisulfuron 0.142 oz prosulfuron	0.57 oz Beacon 75WG 0.25 oz Peak 57WG
Surpass 100 5L	3.0 lb acetochlor 2.0 lb atrazine	2.6 qt	1.95 lb acetochlor 1.30 lb atrazine	1.22 qt Surpass 6.4EC 1.30 qt atrazine 4L

[a]Use only on IMI-corn hybrids (imidazolinone-tolerant, -resistant).

Table 15.04. Soybean Herbicide Premixes, or Co-packs, and Equivalents

Herbicide	Components (a.i./gal or lb)	If you apply (per acre) . . .	You have applied (a.i.)	An equivalent rate of
Axiom 68DF	0.544 FOE-5043 0.136 metribuzin	13 oz	7.07 oz FOE-5043 1.77 oz metribuzin	7.07 oz a.i. FOE-5043 2.36 oz Sencor 75DF
Broadstrike + Dual 7.67EC	0.20 lb flumetsulam 7.47 lb metolachlor	2.5 pt	1.00 oz flumetsulam 2.33 lb metolachlor	1.25 oz Python 80WG 2.33 pt Dual 8EC
Broadstrike + Treflan 3.65EC	0.25 lb flumetsulam 3.40 lb trifluralin	2.25 pt	1.12 oz flumetsulam 0.96 lb trifluralin	1.41 oz Python 80WG 1.91 pt Treflan 4EC
Canopy 75DF	0.107 lb chlorimuron 0.643 lb metribuzin	6 oz	0.64 oz chlorimuron 3.86 oz metribuzin	2.57 oz Classic 25DF 5.14 oz Lexone 75DF
Canopy XL 56.3DF	0.094 chlorimuron 0.469 sulfentrazone	6.8 oz	0.64 oz chlorimuron 3.19 oz sulfentrazone	2.57 oz Classic 25DF 4.25 oz Authority 75DF
Conclude B & G (co-pack)	B = (2.67 lb bentazon + 1.33 lb acifluorfen) G =1.5 lb sethoxydim	1.5 pt + 1.5 pt	0.50 lb bentazon 0.25 lb acifluorfen 0.28 lb sethoxydim	1.5 pt Storm 4S + 1.5 pt Poast 1.5SC[a]
Detail 4.1EC	0.5 lb imazaquin 3.6 lb dimethenamid	1 qt	2.00 oz imazaquin 14.4 oz dimethenamid	2.86 oz Scepter 70DG 19.2 fl oz Frontier 6.0EC
Fusion 2.56EC	2 lb fluazifop 0.56 lb fenoxaprop	8 fl oz	2.00 oz fluazifop 0.56 oz fenoxaprop	8 fl oz Fusilade DX 2EC 6.7 fl oz Option II 0.67EC
Galaxy 3.67SC	3.00 lb bentazon 0.67 lb acifluorfen	2 pt	0.75 lb bentazon 0.17 lb acifluorfen	1.5 pt Basagran 4SC 0.67 pt Blazer 2SC
Manifest B & G (co-pack)	B = (3.00 lb bentazon + 0.67 lb acifluorfen) G = 1.5 lb sethoxydim	2 pt + 1.5 pt	0.75 lb bentazon 0.17 lb acifluorfen 0.28 lb sethoxydim	2 pt Galaxy 3.67SC + 1.5 pt Poast 1.5SC[a]
Pursuit Plus 2.9EC	0.2 lb imazethapyr 2.7 lb pendimethalin	2.5 pt	1.00 oz imazethapyr 0.84 lb pendimethalin	4 fl oz Pursuit 2SC 2.00 pt Prowl 3.3EC
Rezult B & G (co-pack)	B = 5.0 lb bentazon G = 1.0 lb sethoxydim	1.6 pt 1.6 pt	1.00 lb bentazon 0.20 lb sethoxydim	2.0 pt Basagran 4SC 1.6 pt Poast Plus 1SC
Scepter O.T. 2.5SC	0.5 lb imazaquin 2.0 lb acifluorfen	1.0 pt	1.00 oz imazaquin 0.25 lb acifluorfen	1.44 oz Scepter 70DG 1 pt Blazer 2SC
Squadron 2.33EC	0.33 lb imazaquin 2.00 lb pendimethalin	3.0 pt	1.98 oz imazaquin 0.75 lb pendimethalin	2.83 oz Scepter 70DG 1.82 pt Prowl 3.3EC
Steel 2.59EC	2.25 lb pendimethalin 0.17 lb imazethapyr 0.17 lb imazaquin	3.0 pt	0.84 lb pendimethalin 1.00 oz imazethapyr 1.00 oz imazaquin	2.00 pt Prowl 3.3EC 4 fl oz Pursuit 2SC 1.46 oz Scepter 70DG
Stellar 3.1EC	2.4 lb lactofen 0.7 lb flumiclorac	5 fl oz	1.50 oz lactofen 0.44 oz flumiclorac	6 fl oz Cobra 2EC 4 fl oz Resource 0.86EC

Table 15.04. Soybean Herbicide Premixes, or Co-packs, and Equivalents (cont.)

Herbicide	Components (a.i./gal or lb)	If you apply (per acre) . . .	You have applied (a.i.)	An equivalent rate of
Storm 4SC	2.67 lb bentazon 1.33 lb acifluorfen	1.5 pt	0.50 lb bentazon 0.25 lb acifluorfen	1 pt Basagran 4SC 1 pt Blazer 2SC
Synchrony STS 42DF	0.318 lb chlorimuron 0.102 lb thifensulfuron	0.5 oz	0.159 oz chlorimuron 0.051 oz thifensulfuron	0.64 oz Classic 25DF 0.20 oz Pinnacle 25DF
Tri-Scept 3EC	0.43 lb imazaquin 2.57 lb trifluralin	2.33 pt	2.00 oz imazaquin 0.75 lb trifluralin	2.86 oz Scepter 70DG 1.50 pt trifluralin 4EC
Turbo 8EC	6.55 lb metolachlor 1.45 lb metribuzin	2.75 pt	2.25 lb metolachlor 8.00 oz metribuzin	2.25 pt Dual 8EC 10.0 oz Sencor 75DF

[a]1.5 pt of Poast 1.5SC is equivalent to 2.25 pt of Poast Plus 1SC.

labels usually specify to use 10 to 40 gallons of water per acre for ground application and a minimum of 5 gallons per acre for aerial application. Spray pressures of 30 to 60 psi are often suggested with flat-fan or hollow-cone nozzles to produce small droplets and improve canopy penetration. *These small droplets are subject to drift.*

Crop size limitations may be specified on the label to minimize crop injury and maximize weed control. If weeds are smaller than the crop, basal-directed sprays may minimize crop injury because they place more herbicide on the weeds than on the crop. If the weeds are taller than the crop, rope-wick or sponge-type applicators may be used to place the herbicide on top the weeds and minimize contact with the crop. Follow the label directions and precautions for each herbicide.

Herbicide adjuvants, such as crop oil concentrate (COC), nonionic surfactant (NIS), or ammonium fertilizer adjuvant, may be specified on the herbicide label. Crop oil concentrates spread the herbicide across the leaf surface, keep the surface moist longer, and aid penetration into the cuticle. COCs are phytobland oils with emulsifier (surfactant) added to allow better mixing with water. The oil may be of petroleum (POC) or vegetable (VOC) origin. Methylated seed oils (MSO) are esters of fatty acids formulated to provide better performance than a conventional VOC. Most labels allow POC, MSO, or VOC, but Assure II and Matador specify a POC only. COCs are used at 1 to 3 pints per acre or about 1 percent on a volume basis. Oils generally have a greater postemergence effect than surfactants do *on both weeds and crops.*

Surfactants cause a spreading and wetting action by decreasing the surface tension of water, allowing the spray mix to spread over waxy or hairy leaf surfaces rather than forming droplets. Because more leaf surface is covered, more herbicide may be absorbed. Surfactants may contain fatty acids to improve penetration. Labels may specify that the NIS should contain a minimum of 75 to 85 percent active ingredient or else you should use a higher surfactant rate. An NIS usually is applied at 0.25 to 1 pint per acre or ⅛ to ½ percent on a volume-to-volume basis.

Ammonium fertilizer adjuvants are added to increase herbicide activity on weed species such as velvetleaf. Urea ammonium nitrate solution (28-0-0 UAN) is the most common fertilizer adjuvant, although ammonium polyphosphate (10-34-0 APP) or ammonium sulfate (AMS) may also be specified. UAN usually is used at 2 to 4 quarts per acre. Contact herbicide labels may specify that a fertilizer adjuvant replaces an NIS or COC, while translocated herbicides usually specify UAN in addition to an NIS or COC.

Drift-reduction agents are added to the spray tank to reduce small-droplet formation and thus reduce spray-particle drift. See the adjuvant label for rates, as drift retardants vary greatly in formulation.

Conservation Tillage and Weed Control

Conservation tillage allows crop production while reducing soil erosion by protecting the soil surface with plant residue. Minimum or reduced tillage refers to any tillage system leaving crop residue on the soil

surface, including primary tillage with chisel plows or disks and the use of field cultivators, disks, or combination tools for secondary tillage. Mulch tillage is reduced tillage that leaves at least 30 percent of the soil surface covered with plant residue.

Ridge tillage and zero tillage are conservation tillage systems with no major tillage prior to planting. In ridge tillage, conditions are often ideal for banding preemergence herbicides because cultivation is a part of the system. "No-till" is actually "slot tillage" for planting with no overall primary or secondary tillage. No-till planting conserves moisture, soil, and fuel. It also allows timely planting of soybeans or sorghum after winter wheat harvest (double-cropping).

If tillage before planting is eliminated, undesirable existing vegetation must be controlled with herbicides either before, at, or after planting. The elimination or reduction of preplant tillage and row cultivation puts a greater reliance on chemical weed control. Greater emphasis may be placed on preplant or postplant soil-applied herbicides that are not incorporated or on foliar-applied herbicides. Herbicides are now available to allow "total postemergence" weed control in corn and soybeans.

Where primary tillage is minimized, soil-residual herbicides applied several weeks before planting may reduce the need for a "knockdown" herbicide. However, early preplant (EPP) application may require additional preemergence or postemergence herbicides or cultivation for satisfactory weed control after planting. See the "Early Preplant Herbicides Not Incorporated" sections for corn and soybeans for more details.

Corn and soybeans are the primary crops in Illinois, and they are often planted in sequence. Modern equipment allows successful no-till planting in corn and soybean stubble. The use of a disk or chisel plow on corn stubble may still provide adequate crop residue to meet mulch-till requirements.

Soybean stubble is often ideal for minimum- or zero-tillage production systems. Primary tillage is rarely needed, and the crop residue, if properly spread, should not interfere with herbicide distribution. Early preplant application of preemergence herbicides or the use of postemergence herbicides often provides adequate weed control.

The existing vegetation in corn and soybean stubble is usually annual weeds. If small, weeds often can be controlled before planting with herbicides that have both foliar and soil-residual activity. For corn, these include atrazine, premixes containing atrazine, and Balance. Sencor or Lexone (metribuzin), Canopy (metribuzin + chlorimuron), and Canopy XL (sulfentrazone + chlorimuron) may be used before

Table 15.05. Control Ratings for No-Till Herbicides to Control Existing Vegetation

	Annual grasses			Annual broadleaves							Perennial broadleaves			
Herbicide	Brome, downy	Foxtail, giant	Rye or wheat cover	Lambsquarters	Lettuce, prickly	Marestail (horseweed)	Mustards	Ragweed, common	Ragweed, giant	Smartweeds	Alfalfa sod	Clover, red	Dandelion	Vetch, hairy
glyphosate-12[a]	9	9	8	8	7	7	8	7	8	7	5	6	5	6
glyphosate-24[b]	9+	9+	9	9	8	9	9	9	9	8	6	7	7	7
glyphosate + 2,4-D	9	9	9	9	9	9	9	9	9	8	7	8	8	8
Gramoxone	7	8	6	8	6	6	7	8	7	5	N	6	4	6
Gramoxone + atrazine	8	9	8	9	9	9	9	9	9	9	4	7	6	8
2,4-D ester, 1 pint	N	N	N	9	8	8	9	9	8	6	6	9	8	8
Banvel/Clarity	N	N	N	9	9	7	7	9	9	9	8	9	7	9
2,4-D + Banvel	N	N	N	9	9	8	9	9	9	8	8	9	8	9
Marksman	6	5	N	9	9	9	8	9	9	9	8	9	7	9
Atrazine	7	7	6	9	9	8	8	9	9	9	N	6	4	7
Balance	6	8	5	8	8	8	8	8	6	8	N	N	6	N
Canopy	N	5	N	9	9	8	9	9	8	9	4	5	7	5
Canopy XL	N	6	N	9	9	9	9	9	8	9	N	4	4	6
Sencor, Lexone	5	5	4	7	8	6	8	7	6	8	N	5	6	5

Control ratings: 9 = excellent, 8 = good, 7 = fair, 6 = poor, 5 or 4 = unsatisfactory. N = Nil or None. Boldface indicates acceptable control.
[a]glyphosate 12 oz a.e./A = 16 fl oz/A Roundup Ultra or 14.5 fl oz Touchdown 5.
[b]glyphosate 24 oz a.e./A = 32 fl oz/A Roundup Ultra or 29.0 fl oz Touchdown 5.

soybean emergence (see Table 15.05). *Do not apply after soybean emergence.* Foliar activity is enhanced by adding a COC or an NIS. See the herbicide label for specific adjuvant recommendations. The use of 28-0-0 UAN as a carrier also increases annual weed knockdown.

Annual vegetation more than 2 to 3 inches tall at planting may require a contact or a translocated herbicide (Table 15.05). Gramoxone Extra, Roundup Ultra, or Touchdown 5 may be used with most preemergence herbicides to control existing vegetation. To control broadleaf weeds, 2,4-D may be used prior to planting corn or no-till soybeans, and Banvel may be used in the spring prior to corn *but not soybeans.*

Roundup Ultra or **Touchdown 5** (glyphosate) may be used to control existing vegetation prior to planting. Small annual weeds can be controlled with 1 to 2 pints of Roundup Ultra or Touchdown 5. Use higher rates on larger weeds and when mixing with residual herbicides. Higher rates can also suppress or control some perennial weeds. Spray volume per acre should be 10 to 40 gallons. **FieldMaster** (glyphosate + acetochlor + atrazine) is used in corn at 3.5 to 5 quarts per acre.

Gramoxone Extra[RUP] 2.5S (paraquat) is used at 1.5 to 3 pints per acre to control existing vegetation before planting. Apply with an NIS or COC in at least 10 to 20 gallons of spray per acre. The addition of a photosynthetic inhibitor herbicide such as atrazine or metribuzin can improve control of smartweeds, giant ragweed, and marestail (horseweed).

Banvel or **Clarity** (dicamba) or **2,4-D** may be used in the fall or spring before planting corn or in the fall before planting soybeans to control annual and some perennial broadleaf plants, including clovers and alfalfa. A combination of dicamba plus 2,4-D can often control more weeds at lower cost. 2,4-D also may be used in the spring before planting no-till soybeans. *See the current 2,4-D label or the "Early Preplant Herbicides Not Incorporated (Soybeans)" section.*

Annual cover crops in Illinois are hairy vetch, winter rye, and winter wheat. Hairy vetch, a winter annual legume, is easily controlled with 2,4-D or dicamba before planting corn. Winter rye or winter wheat can be controlled by glyphosate prior to planting corn or soybeans. Cover crops should be controlled prior to planting crops, but the question is, "How early do we do this?" If the season is dry, late control depletes soil moisture for crop establishment, but if the season is wet, late control helps dry out the soil. Decomposing residue of small-grain cover crops can sometimes inhibit corn seedlings.

Perennial sods require a different approach. It is estimated that 65 to 70 percent of the Conservation Reserve Program (CRP) acres in the Corn Belt may return to cropland. Many of these acres have been planted to perennial grass or legume sods. The questions here are these: What is the best way to control sod species? What is the best timing for control, and what are the best cropping choices? *Sods should be killed prior to planting crops into them* (Table 15.06).

Table 15.06. Control of Perennial Grass and Legume Sods Before No-Till Crop Production

Herbicide	Rate/ acre	Alfalfa	Blue-grass	Brome, smooth	Clover, red	Fescue, tall	Orchard-grass	Quack-grass	Timothy
glyphosate, fall	48 oz[b]	8	9+	9	9	9	9	9	9
glyphosate, fall	24 oz[a]	7	9	7	7	7	8	9	9
+ 1 pt 2,4-D		8	9	6	9	6	7	8	8
+ 0.5 pt Banvel		8	9	6	9	6	7	8	8
+ 1 pt Banvel		9	9	6	9	6	7	8	8
glyphosate, fall + spring	24 oz/24 oz[a]	8	9+	9+	9	9	9	9	9
glyphosate, spring	48 oz[b]	6	9	8	7	7	6	9	8
glyphosate, spring	24 oz a.e.[a]	5	8	6	5	6	6	7	7
+ 1 pt 2,4-D		7	8	5	8	5	5	6	7
+ 0.5 pt Banvel		8	8	5	9	5	5	6	7
Gramoxone, spring	3 pt	N	6	4	7	7	4	4	6
Gramoxone, spring	2.0 pt	N	5	N	6	5	N	N	5
+ 2 lb atrazine		5	9	7	8	8	7	7	8

Control ratings: 9 = excellent, 8 = good, 7 = fair, 6 = poor, 5 or 4 = unsatisfactory. N = Nil or None. Boldface indicates acceptable control.

[a]glyphosate 24 oz a.e./A = 32 fl oz/A Roundup Ultra or 29 fl oz/A Touchdown 5.

[b]glyphosate 48 oz a.e./A = 64 fl oz/A Roundup Ultra or 58 fl oz/A Touchdown 5.

Perennial grass sods were planted on much of the CRP land. Roundup Ultra and Touchdown (glyphosate) provide the best "sod grass" control. *Fall application is more effective than spring.* Mowing the sod in late summer allows adequate regrowth for timely fall application. Active regrowth should be 6 to 8 inches before fall application. Spring applications must be delayed to obtain 6 to 10 inches of new growth for effective control. In the spring, Gramoxone Extra + atrazine is often as effective as glyphosate for controlling several grass species (Table 15.06). Preplant glyphosate rates may be reduced if followed with atrazine at corn planting. If grass-legume mixes are established, the legume component must also be controlled.

Perennial legume sods must have 6 to 8 inches of new growth for effective control. *Do not take a spring cutting before controlling legumes,* as this delays corn planting. Corn will better utilize legume nitrogen and allows preplant or postemergence use of 2,4-D or dicamba. Dicamba controls alfalfa better than 2,4-D does, but both control red clover. When glyphosate is used, adding dicamba improves alfalfa control and adding 2,4-D improves dandelion control. Roundup Ultra may be applied before the last alfalfa cutting in the fall or spring. Clover sods may be controlled by atrazine (see Tables 15.05 and 15.06).

Herbicides for Corn

Herbicides mentioned in this section are registered for use on field corn. Most are also registered for silage corn. See Tables 15.08, 15.13, and 15.14 for registered tank mixes. Herbicide suggestions for sweet corn and popcorn may be found in the *Illinois Agricultural Pest Management Handbook,* Chapter 10, "Weed Control for Commercial Vegetable Crops." Growers producing hybrid seed corn should check with the contracting company or the producer of inbred seed about tolerance of the parent lines. Rates of

Table 15.07. Corn Herbicides: Preplant or Preemergence Rates Per Acre

Herbicide	Unit	1% OM sandy loam[a]	1–2% OM silt loam[b]	3–4% OM silty clay loam[c]	5–6% OM silty clay[c]
Atrazine 4L	qt	2.0	2.0	2.0	2.0
Atrazine 90DF	lb	2.2	2.2	2.2	2.2
Axiom 68WSG	oz	13	15	19	23
Balance 75WDG	oz	No	2–2.5	2–2.5	2–2.5
Banvel 4S	pt	No[d]	No[d]	1.0	1.0
Bicep II 5.9L	qt	1.5	1.8	2.4	3.0
Bicep II Magnum 5.5L	qt	1.3	1.6	2.1	2.6
Bicep Lite 4.9L	qt	1.5	1.8	2.4	3.0
Bicep Lite II Magnum 6L	qt	0.9	1.1	1.5	1.9
Broadstrike + Dual 7.67E	pt	1.75	2.00	2.25	2.50
Bullet 4L	qt	2.5	3.0	4.0	4.5
Contour[e] 3.38L	pt	1.33	1.33	1.33	1.33
Cyanazine[f] 4L	qt	1.0[g]	1.0	1.0	1.0
Cyanazine[f] 90DF	lb	1.1[g]	1.1	1.1	1.1
DoublePlay 7E	pt	4.5[h,i]	4.5[h]	4.5[h]	4.5[h]
Dual II 7.8E	pt	1.5	2.0	2.5	3.0
Dual II Magnum 7.62L	pt	1.0	1.33	1.67	2.0
Eradicane 6.7E	pt	4.75	4.75[h]	4.75[h]	4.75[h]
Extrazine II[j] 4L	qt	1.3[g]	1.3	1.3	1.3
Extrazine II[j] 90DF	lb	1.5[g]	1.5	1.5	1.5
Frontier 6.0E	fl oz	16	20	28	32
FulTime 4L	qt	2.5[i]	3.0	4.0	5.0
Guardsman/LeadOff 5L	pt	2.5	3.0	4.5	5.0
Harness 7E	pt	1.5[i]	2.0	2.5	2.75
Harness Xtra 5.6L	qt	1.4[i]	2.0	2.5	3.0

Table 15.07. Corn Herbicides: Preplant or Preemergence Rates Per Acre (cont.)

Herbicide	Unit	1% OM sandy loam[a]	1–2% OM silt loam[b]	3–4% OM silty clay loam[c]	5–6% OM silty clay[c]
Hornet 85.6WG	oz	3.2	4.0	4.8	4.8
Lasso 4E	qt	2.0	2.25	2.75	3.25
Marksman 3.3L	pt	No[d]	No[d]	3.5	3.5
Micro-Tech 4CS	qt	2.0	2.25	2.75	3.25
OpTill 6E	fl oz	22[i]	26	34	38
Partner 65WG	lb	3.0	3.5	4.0	5.0
Pentagon 60WG	lb	1.5	2.5	3.0	3.3
Princep 90DF	lb	2.2	2.6	3.3	4.0
Prowl 3.3E	pt	2.0	3.0	4.0	4.8
Pursuit Plus[e] 3E	pt	2.5	2.5	2.5	2.5
Python 80WDG	oz	0.8[g]	1.0[g]	1.25	1.33
Surpass 6.4E	pt	1.5[i]	2.0	2.5	3.0
Surpass 100 5L	qt	1.6[i]	2.0	2.6	3.3
Sutan+ 6.7E	pt	4.75	4.75[h]	4.75[h]	4.75[h]
TopNotch 3.2CS	qt	2.0[i]	2.25	2.5	3.0

OM = organic matter in the soil.
[a]Characteristic of most sandy soils in Illinois.
[b]Characteristic of many Illinois soils south of Interstate 70.
[c]Characteristic of many "prairie soils" in northern Illinois.
[d]If planted to no-till corn, may use 0.5 pt Banvel or 2 pt Marksman.
[e]Use only on IMI-designated corn hybrids.
[f]Cyanazine is sold as Bladex or Cy-Pro.
[g]May cause crop injury on this soil.
[h]Use a higher rate (see label) for heavy infestations and certain weeds.
[i]Do not use if groundwater is within 30 ft of surface.
[j]Cy-Pro AT is a product similar to Extrazine II.

Table 15.08. Soil-Applied Corn Herbicide Tank Mixes and Application Timing

	Atrazine	Balance	Banvel/Clarity or Marksman	Contour[a] or Pursuit[a]	Cyanazine or Extrazine II[b]	Hornet	Simazine
used alone	1,2,3	1,2	2,3	1,2,3	1,2,3[c]	1,2,3	1,2
atrazine	—	1,2	—	1,2	1,2	—	1,2
Axiom	1,2	—	2	—	1,2	1,2	—
Balance	1,2	—	2	—	1,2	—	1,2
DoublePlay	1	—	—	1	1	1	—
Dual II Magnum	1,2,3	1,2	2,3	1,2,3	1,2	1,2	1,2
Eradicane, Sutan+	1	1	—	1	1	1	1
Frontier	1,2,3	1,2	2,3	1,2,3	1,2	1,2	1,2
Harness	1,2,3	1,2	2,3	1,2,3	1,2	1,2	1,2
Micro-Tech, Lasso	1,2,3	1,2	2,3	1,2,3	1,2	1,2	1,2
Prowl, Pentagon	2,3	2	2,3	2,3	2,3[c]	—	2
Surpass, TopNotch	1,2,3	1,2	2,3	1,2,3	1,2,3[c]	1,2	1,2

1 = preplant incorporated; 2 = early preplant not incorporated or preemergence; 3 = early postemergence.
[a]Use only with IMI-designated corn hybrids.
[b]Cy-Pro AT is a similar product.
[c]Use DF (not 4L) formulation of cyanazine postemergence.

preplant and preemergence herbicides to use on several typical Illinois soils are given in Table 15.07. See Tables 15.09, 15.10, 15.11, and 15.12 for weeds controlled by the herbicides used in corn.

Early Preplant Herbicides Not Incorporated (Corn)

Early preplant applications in no-till corn programs are used to minimize existing vegetation problems and reduce the need for a burndown herbicide at planting. Atrazine has both foliar and soil activity, so it may control small annual weeds (Table 15.05) prior to planting corn, especially if a COC is added to the spray mix or if 28-0-0 UAN is used as a spray carrier.

Atrazine^RUP^, Axiom, Bicep II Magnum^RUP^, Bullet^RUP^, Dual II Magnum, Frontier, Guardsman^RUP^, Harness^RUP^, Harness Xtra^RUP^, LeadOff^RUP^, or **Micro-Tech^RUP^** may be applied within 30 days of planting as a single full-rate application or within 45 days if the application is split, before and at planting. **Topnotch^RUP^** or **FulTime^RUP^** may be applied within 40 days, and **Broadstrike + Dual, Hornet, OpTill, Python, Surpass^RUP^,** or **Surpass 100^RUP^** within 30 days of planting corn. **Contour^RUP^** or **Pursuit** may be applied within 45 days of planting IMI (imidazolinone-tolerant or -resistant) corn. **Balance^RUP^ 75WDG** may be applied 14 days before planting corn. These herbicides are discussed further in the upcoming sections on soil-applied herbicides.

2,4-D ester, dicamba, Gramoxone Extra^RUP^, Roundup Ultra, or **Touchdown** should be added to the spray mix if weeds are over 2 to 3 inches tall (check label recommendations for individual species). These herbicides are discussed in the "Conservation Tillage and Weed Control" section of this chapter. See Table 15.05 for weeds controlled by these herbicides.

Soil-Applied "Grass" Herbicides (Corn)

The common soil-applied grass herbicides are acetamides or thiocarbamates, which are seedling growth inhibitors. **Eradicane** (EPTC) and **Sutan+** (butylate) are thiocarbamates, whereas **DoublePlay^RUP^ 7E** is a premix of EPTC plus acetochlor. They all require incorporation into the soil within 4 hours to minimize surface loss. Apply within 2 weeks of expected planting date. Rates per acre are in Table 15.07.

Acetamide herbicides for corn are acetochlor, alachlor, dimethenamid, FOE-5043, and metolachlor, which control annual grasses (Table 15.09) and some small-seeded broadleaf weeds. To improve broadleaf weed control, all acetamide herbicides, except FOE-5043, are formulated as premixes with atrazine, and all may be tank-mixed with atrazine or some other herbicides (Table 15.08). Most acetamides may be used preplant (surface or incorporated), preemergence, and early postemergence. If they are not incorporated and adequate rainfall does not occur soon after applying, consider rotary hoeing or cultivation if the cropping plan and planting pattern allow.

Dual II 7.8E (metolachlor) is applied at 1.5 to 4 pints per acre, or use 6 to 16 pounds of Dual II 25G. **Bicep II^RUP^ 5.9L** and **Bicep Lite II^RUP^ 4.9L,** 5:4 and 2:1 premixes, respectively, of metolachlor:atrazine, are used at 1.5 to 3 quarts per acre. **Magnum** formulations contain S-metolachlor, the active isomer. Use rates per acre are **Dual II Magnum 7.64E** at 1.5 to 2 pints, **Bicep II Magnum^RUP^ 5.5L** at 1.3 to 2.6 pints, and **Bicep Lite II Magnum^RUP^ 6L** at 0.9 to 2.2 pints. These herbicides all contain benoxacor, a safener to minimize corn injury.

Harness^RUP^ 7E or **Surpass^RUP^ 6.4E** (acetochlor) is applied at 1.25 to 3 pints of Harness or 1.5 to 3.75 pints per acre of Surpass. **TopNotch^RUP^ 3.2CS** (encapsulated) is used at 2 to 3.25 quarts per acre. **Surpass 100^RUP^ 5L** and **FulTime 4L,** 3:2 premixes of acetochlor:atrazine, are used at 1.6 to 3.3 quarts and 2.5 to 5 quarts per acre, respectively. **Harness Xtra^RUP^ 5.6L,** a 6:5 premix of acetochlor:atrazine, is used at 1.4 to 3 quarts per acre. All acetochlor products contain crop safeners to minimize corn injury. *Do not apply acetochlor to very sandy soils with a high water table. Read the label closely for further restrictions, including setbacks.*

Lasso^RUP^ 4E or **Micro-Tech^RUP^ 4CS** (alachlor) is applied at 2 to 4 quarts per acre, or 16 to 26 pounds of Lasso II 15G. **Bullet^RUP^ 4L** is a 5:3 premix of alachlor:atrazine used at 2.5 to 5 quarts per acre. Bullet and Micro-Tech contain encapsulated alachlor to increase persistence and reduce corn injury.

Frontier (dimethenamid) **6E** is applied at 18 to 32 fluid ounces per acre. **Guardsman^RUP^** or **LeadOff^RUP^ 5L,** a 7:8 premix of dimethenamid:atrazine, is used at 2.5 to 5 pints per acre. **OpTill 6E,** a 5:1 dimethanamid:dicamba premix, is applied preplant surface at 22 to 38 fluid ounces per acre.

Axiom 68DF (4:1 FOE-5043:metribuzin) is applied at 13 to 23 ounces per acre. Higher rates are for conservation tillage systems. A tank mix with atrazine will increase broadleaf weed control.

Prowl 3.3E (pendimethalin) is used preemergence after planting corn, *but do not use preplant or incorporate.* Corn should be planted at least 1.5 inches deep. The Prowl rate is 1.8 to 4.8 pints per acre alone or 1.8 to 3.6 pints per acre in tank-mix combinations.

Balance^RUP^ 75WDG (isoxaflutole) is used preplant incorporated or preemergence at 1.5 to 3 ounces to control several annual grasses in corn (Table 15.09). Do not apply after corn emergence or on sandy soils.

Table 15.09. Corn Herbicides: Grass and Nutsedge Control Ratings

	Annuals								Perennials				
Herbicide	Barnyardgrass	Crabgrass	Cupgrass, woolly	Foxtail, giant	Foxtail, yellow	Panicum, fall	Sandbur	Shattercane	Johnsongrass	Muhly, wirestem	Nutsedge, yellow	Quackgrass	Corn response
Soil-applied													
Axiom	9	9	7	9	9	9	6	5	N	N	6	N	1+
Dual II Magnum	9	9	7	9	9	9	6	5	N	N	8	N	1
Frontier	9	9	7	9	9	9	6	5	N	N	7	N	1+
Harness	9	9	8	9	9	9	7	5	N	N	8	N	1+
Lasso/Micro-Tech	9	9	7	9	9	9	6	5	N	N	7	N	1+
Surpass, TopNotch	9	9	8	9	9	9	7	5	N	N	8	N	1+
DoublePlay	9	9	8	9	9	9	8	8	6	4	7	6	1+
Eradicane, Sutan+	9	9	8	9	9	9	8+	8	7	6	8	6	1
Prowl, Pentagon	8+	8+	8	8+	9	8+	8	7	N	N	N	N	1+
Balance	8	7	8	8	7	8	6	5	N	N	N	N	1
Atrazine	7	5	4	7	7	3	6	N	N	5	6	6	0
Princep	8	7	4	8	8	7	5	4	N	6	6	6	0
Postemergence	.... *See Table 15.11 for maximum grass sizes*												
Accent[a] or Celebrity[a]	8	5	8	8+	8	8	8	9	8+	7	6	8	1+
Accent Gold[a]	8+	6	6	8	8	8	7	8	7	7	6	7	2
Basis[a]	7	6	5	8	8	8	6	8	4	5	4	4	2
Basis Gold[a]	8+	6	6	8+	8	8	7	8	7	6	5	7	2
Beacon[a]	4	4	N	6	5	7	6	9	8	5	6	8	2
Lightning[b]	8	7	8	8+	8	8	7	9	6	N	6	5	1+
Resolve[b]	7	7	6	8	6	6	4	8	5	N	5	N	1+
Poast Plus[c]	9	9	9	9	9	9	9	8+	7	7	N	7	0
Atrazine + oil	7	5	6	7	7	4	6	N	N	4	7	6	1+
Liberty[d]	7	8	8	8+	7	7	7	8	6	7	5	5	1
Liberty ATZ[d]	7	8	8	9	7	6	7	7	5	6	7	6	1
Roundup Ultra[e]	9	9	8+	9	9	9	9	9	9	8+	7	8+	1

Control ratings: 9 = excellent, 8 = good, 7 = fair, 6 = poor, 5 or 4 = unsatisfactory, N = Nil or None. Boldface indicates acceptable control.
Corn response: 0 = minimal, 1 = possible, 2 = probable, 3 = serious.
[a]Use of IR (imidazilinone-resistant) corn hybrids minimizes insecticide interaction and injury.
[b]Use only with IMI-designated corn hybrids.
[c]Use only with PP- or SR-designated corn hybrids.
[d]Use only with Liberty Link or GR-designated (glufosinate-resistant) corn hybrids.
[e]Use only with Roundup Ready–designated corn hybrids.

Soil-Applied "Grass" Herbicides Applied After Corn Emergence

Atrazine plus Dual II, Frontier, Harness, Micro-Tech, Surpass, or TopNotch—or their respective premixes of Bicep II, Guardsman or LeadOff, Harness Extra, Bullet, Surpass 100, or FulTime—may be applied after planting until corn is 5 to 12 inches tall (depending on the herbicide). Grass weeds should be less than 1.5 inches tall or not exceeding the 2-leaf stage unless the soil-applied "grass" herbicide to minimize problems with late-emerging grasses is applied with a post-emergence grass herbicide such as Accent to control

larger grasses. See labels for corn size limitations. Split applications of Dual II are used in "seed corn" to prevent late-emerging grass problems. *Do not use liquid fertilizer as the carrier after corn emergence.*

Prowl or **Treflan** may be applied from the 2-leaf stage of field corn (4 inches tall) up to last cultivation (layby); this use has been primarily in sandy soils where shattercane and crabgrass are late-emerging problems. See the label for exact instructions and the need for incorporation. *Do not use Prowl in corn more than once per crop season.*

Soil-Applied "Broadleaf" Herbicides (Corn)

AAtrex^{RUP} or **Atrazine^{RUP}** (atrazine), or **Princep** (simazine), is often incorporated before planting because solubility is low. Atrazine is used alone at 4 pints of 4L or 2.2 pounds of 90DF (2.0 pounds active ingredient/a.i.) per acre, except on highly erodible land (HEL) with less than 30 percent residue cover, where 1.6 pounds a.i. per acre is the maximum allowed. When mixed with "grass" herbicides (Table 15.08), the atrazine rate to control broadleaf weeds is 2 to 3 pints of 4L or 1.1 to 1.8 pounds of 90DF. A 1:1 mixture of atrazine and simazine is often used in southern Illinois.

Atrazine or simazine can persist to injure some rotational crops. The risk of carryover is greater with late application; a cool, dry growing season; or both; and on soils with pH over 7.2. Soybeans planted the next year may show injury from atrazine carryover, especially if atrazine is applied after June 10. Depending on rate and season, corn or sorghum may be a better choice. *Do not plant small grains, clovers, alfalfa, or vegetables in the fall or the next spring after using atrazine.*

Bladex^{RUP} or **Cy-Pro^{RUP}** (cyanazine) and **Extrazine II^{RUP}** or **Cy-Pro AT^{RUP}** (cyanazine + atrazine) are under a phaseout program through 2002. Beginning in 1999, total cyanazine rates allowed per year (all applications) are 1 lb a.i. per acre, limiting cyanazine's usefulness as a soil-applied herbicide. All products containing atrazine and cyanazine are restricted-use pesticides because of the risk of groundwater and surface water contamination.

Best management practices (BMP) to protect groundwater and surface water are mandated on labels of cyanazine or atrazine and all premixes containing atrazine. *Required buffer zones (setbacks) are as follows:* No application is allowed within 66 feet of points where field surface water can enter perennial or intermittent streams and rivers (if HEL, this 66 feet must be in crops or grass, i.e., a filter strip) or within 200 feet of lakes and reservoirs. No mixing or loading is allowed within 50 feet of streams, rivers, lakes, or reservoirs.

Maximum allowable atrazine rates are lowest for highly erodible land with less than 30 percent plant residue cover (HEL < 30 percent PRC), where the maximum rate is 1.6 pounds a.i./acre soil-applied or 2.0 pounds a.i./acre postemergence. On other soils, the maximum atrazine rate is 2 pounds a.i./acre and a total of 2.5 pounds a.i./year for all soils.

Premixes containing atrazine make calculations of total annual use difficult, especially if both soil-applied and postemergence premixes are used. Pounds of active ingredient of atrazine per pound or gallon of corn herbicide premix are listed in Table 15.03. For example, if you apply Bicep II 5.9L at 2.4 quarts (1.60 pounds a.i. atrazine) and Marksman 3.2L at 3.5 pints (0.92 pounds a.i. atrazine) per acre, you have applied a total of 2.52 pounds a.i. of atrazine per acre. This combination is slightly above the 2.50 pounds a.i. of atrazine allowed per year on any soil.

Balance^{RUP} 75WDG (isoxaflutole) may be applied preplant incorporated or preemergence at 1.5 to 2.5 ounces per acre. Do not apply to very sandy soils. Do not apply after corn emergence. Balance may be tank-mixed with several herbicides (Table 15.08) to increase grass control.

Python 80WDG (flumetsulam) or **Hornet 85.6WG** (flumetsulam + clopyralid) at 0.8 to 1.33 ounces or 3.2 to 4.8 ounces per acre, respectively, may be applied prior to planting and incorporated or applied after planting corn. They control only broadleaf weeds (Table 15.10), so they may be tank-mixed with appropriate "grass control" herbicides (see Table 15.08). *Observe label precautions on drift and tank cleanup with Hornet, as it contains clopyralid, the active ingredient in Stinger.* **Broadstrike + Dual 7.67E** (flumetsulam + metolachlor) is used at 1.75 to 2.5 pints per acre. All flumetsulam labels have precautions regarding low and high soil pH as well as soil insecticide use, so consult the label before applying them. *Be sure soil insecticides are applied in a T-band and not placed in-furrow.*

Contour^{RUP} (imazethapyr + atrazine), **Pursuit** (imazethapyr), or **Pursuit Plus** (imazethapyr + pendimethalin) may be used only on IMI-corn hybrids (IR/IMR or IT/PT). Pursuit or Contour may be applied preplant incorporated or preemergence, whereas Pursuit Plus may be used only preemergence on corn. Rates per acre are 1.44 ounces of Pursuit 70DG (½ soluble bag) or 4 fluid ounces of Pursuit 2S (1 gallon = 32 acres), 2.5 pints of Pursuit Plus, or 1.33 pints of Contour (1 gallon = 6 acres).

Banvel or **Clarity** (dicamba), or **Marksman^{RUP}** (dicamba + atrazine), may be applied preemergence, but only on medium- or fine-textured soils containing

at least 2 percent organic matter, where the rate is 1 pint of Banvel or Clarity or 3.5 pints of Marksman per acre. On other soils, *only if the corn is planted no-till,* use 0.5 pint of Banvel or Clarity, or 2 pints of Marksman per acre. Banvel, Clarity, or Marksman may be tank-mixed with preemergence "grass" herbicides (Table 15.08), but do not incorporate.

Postemergence (Foliar-Applied) Herbicides (Corn)

Some postemergence herbicides control certain grass weeds (Table 15.09), whereas others primarily control broadleaf weeds (Table 15.10). Several postemergence herbicide tank mixes are registered (Tables 15.13 and 15.14). Many postemergence corn herbicides allow or require the use of an adjuvant to improve activity. Table 15.16 lists labeled adjuvants, minimum time between applications and rainfall for optimal herbicide activity, and required reentry intervals.

Postemergence Grass and Broadleaf Control (Corn)

Accent, Accent Gold, Basis, Basis Gold, Beacon, Liberty, Liberty ATZ, Lightning, Poast Plus, Pursuit, Resolve, and Roundup Ultra are used postemergence in corn to control some small grass weeds (Tables 15.09 and 15.11). *Lightning, Pursuit, and Resolve require IMI-corn hybrids* (IT/PT or IR/IMR). IR/IMR-designated corn hybrids are not required but may help minimize corn injury (see upcoming discussion) from sulfonylurea or sulfonamide herbicides. Liberty or Liberty ATZ requires Liberty Link or GR corn hybrids. Poast Plus requires PP (Poast Protected) corn hybrids and controls only grasses. Roundup Ultra requires Roundup Ready corn hybrids. See Tables 15.09 and 15.10 for grass and broadleaf weed control and Tables 15.11 and 15.12 for maximum weed sizes.

Accent, Basis, Beacon, Lightning, and Pursuit are ALS inhibitors and *do not control ALS-resistant waterhemp or other ALS-resistant weeds.* Tank mixes (Tables 15.13 and 15.14) or premixes (Table 15.03) of herbicides with different modes of action may help minimize the potential for weeds developing resistance. Tank mixes also improve broadleaf weed control but may antagonize grass control, increase the potential for crop injury, or both. Before applying tank mixes of herbicides or insecticides, *"read and heed" all label precautions* as to climatic conditions, grass species, and adjuvants. *Do not tank-mix most ALS herbicides with bentazon or cyanazine,* and do not apply them within 3 to 7 days after applying bentazon or cyanazine.

Restrictions regarding soil-applied organophosphate (OP) insecticide (used primarily for rootworm control) are similar on the labels of several ALS herbicides (see Table 15.15). Accent, Accent Gold, Basis Gold, or imazethapyr controls giant foxtail, fall panicum, and barnyardgrass better than Basis or Beacon (Tables 15.09 and 15.11).

Basis 75WG (rimsulfuron + thifensulfuron) is used at ⅓ ounce (¼ soluble packet) per acre on field corn *up to the 4-leaf stage or two visible leaf collars (V-2), whichever is most restrictive.* Cultivation is suggested 10 to 15 days after application. A sequential application of Accent is allowed. *Basis has a potential to select for ALS-resistant weed biotypes.*

Basis Gold[RUP] (rimsulfuron + nicosulfuron + atrazine) at 14 ounces or **Accent Gold** (rimsulfuron + nicosulfuron + flumetsulam + clopyralid) at 2.9 ounces (¼ soluble packet of either) per acre may be applied to field corn *up to 12 inches tall or exhibiting 6 leaf collars, whichever is most restrictive.* Cultivate if rain does not occur within 5 to 7 days. A sequential application of Accent is allowed.

Accent 75WG (nicosulfuron) may be applied over the top of corn up to 20 inches tall (freestanding) or with six visible leaf collars, *whichever is most restrictive.* Apply with drop nozzles on corn 20 to 36 inches tall. *Do not apply after corn is 36 inches tall or exhibits 10 leaf collars.* Use ⅔ ounce (¼ soluble bag) per acre. If needed, a second application can be made 14 to 28 days later, but do not exceed 1⅓ ounces per growing season; observe corn size limits. **Celebrity** is a co-pack providing a full rate of Accent plus dicamba to improve broadleaf weed control. Accent and Beacon control quackgrass and johnsongrass. (See upcoming section on perennials.)

Beacon 75WG (primisulfuron) is applied to 4- to 20-inch corn at 0.76 ounce (½ soluble bag) per acre. Split applications (see the label) may provide better control of johnsongrass. The second application must be made before tassel emergence and be directed with drop nozzles if corn is over 20 inches tall.

Roundup Ultra (glyphosate) used at 1.5 to 2 pints per acre on Roundup Ready corn hybrids controls several grass and broadleaf weeds. Total in-crop applications must not exceed 2 quarts. *Apply prior to corn being 30 inches tall or V-8 stage.* See Tables 15.09 and 15.10 for weed ratings.

Contour[RUP] (1:8 imazethapyr:atrazine) or **Resolve** (1:3 imazethapyr:dicamba) is less likely to select for ALS-resistant weed biotypes than **Lightning** (imazethapyr + imazapyr) or **Pursuit** (imazethapyr). *Use only on IMI-corn hybrids (IR or IT).* Rates per acre are 5.33 ounces (⅖ soluble bag) of Resolve, 1.33 pints of Contour, 1.28 ounces (½ soluble bag) of Lightning 70DG, 4 fluid ounces Pursuit 2S, or 1.44 ounces (½ soluble bag) of Pursuit 70DG. Apply before corn is 12

Table 15.10. Corn Herbicides: Broadleaf Weed Control Ratings

Herbicide	Burcucumber	Cocklebur	Jimsonweed	Kochia	Lambsquarters	Morningglories, annual	Nightshade, eastern black	Pigweeds	Ragweed, common	Ragweed, giant	Sida, prickly	Smartweeds	Sunflower, wild	Velvetleaf	Corn response
Soil-applied															
Atrazine[a,b]	6	8	9	9[a]		8	9	9[a]	9	8	9	9	8	7	0
Princep[a,b]	6	8	9	9[a]		8	9	9[a]	9	7	9	9	8	7	0
Marksman	6	8	8	8		8	8	9	9	7	7	9	8	7	2+
Python[d]	N	7	7	8+		5	8	9	7	5	7	8	8	8	1+
Hornet	N	8	8	8		7	8	8	8	8	7	8+	9	8	1+
Balance	N	4	8	9		4	9	9	9	6	6	8	6	9	1
Postemergence	······ *See Table 15.12 for maximum weed sizes* ······														
Contact or triazine[f]															
Aim	—	8	6	—		8	8	8	6	4	—	5	—	9	2
Atrazine[a,b]	8	9	9	9[a]		9	9	9[a]	9	8	8+	9	9	8	1
Buctril	7	9	9	8		8	9	7	8+	8	4	9	9	8	2[e]
Buctril + atrazine	8+	9	9	8		9	9	9	9	9	9	9	9	8+	2[e]
Laddok S-12	6	9	9	8		8	8	8	9	8+	8	9	9	9	1
Liberty[f]	7	9	9	8+		8	8+	8	8+	8	7	8+	9	8	1
Liberty ATZ	7	9	9	8+		9	9	9	9	8+	8	9	9	8	1
Resource	7	7	7	4		5	4	7	7	6	7	5	4	9	1+
Tough	5	8	8	9		4	9	9	6	7	5	5	7	6	1[e]
Plant-growth regulator (PGR)[f]															
Marksman	8	9	9	8+		9	9	9	9	9	9	9	9	8	1[e]
Banvel/Clarity	7	9	9	8+		9	8	9	9	9	8	9	8+	8	1+[e]
2,4-D	N	9	7	7		9	7	9	9	8+	8	6	8	8	2+[e]
Stinger	N	9	8	N		N	7	N	9	9	N	7	8+	N	1[e]
Acetolactate synthetase (ALS)[g]															
Accent[b,c,i]	7	5	8	6		7	N	8	4	N	N	7	4	5	1+
Basis[b,c,i]	N	6	4	6		4	N	8	5	N	N	9	7	8	2
Basis Gold[b,i]	7	8	8	6		7	7	9	8	7	7	9	8	7	2
Beacon[b,c,i]	8+	8	8	8		6	8	8	9	9	7	8	8+	7	2
Exceed[b,c,i]	8+	9	8+	8		7	8	9	9	9	8	9	9	9	1+
Lightning[b,c,h]	6	9	8	8+		7	9	9	7	7	8	8+	9	8+	1+
Permit[c]	5	9	7	7		6	4	9	8	8	7	7	8+	8+	1
Spirit[b,c,i]	8+	8+	8+	8		6	8	8+	9	9	7	8	8+	8+	1+
ALS + PGR[j]															
Accent Gold[b,e]	5	8	7	7		6	7	8	8+	8	7	8	9	8	2[e]
Celebrity[b,h]	8	8	9	8		8	6	9	8+	9	6	9	7	7	2[e]
Hornet	5	8+	7	8		7	7	8	8+	8	7	8+	9	8	1+[e]
NorthStar	8	8	8	8		7	8+	9	9	9	7	8	9	9	1+[e]
Resolve[b,h]	6	9	8+	8		8	9	9	8	8	8	9	8	8	1+
Scorpion III	6	9	8	8		8+	8	9	8+	8	8	9	9	8	1+[e]
Roundup Ultra[k]	7	9	9	8		6	8	9	8+	8+	7	8	8+	8	0

Control ratings: 9 = excellent, 8 = good, 7 = fair, 6 = poor, 5 or 4 = unsatisfactory, N = Nil or None. Boldface indicates acceptable control. Corn response: 0 = minimal, 1 = possible, 2 = probable, 3 = serious.

Table 15.10. Corn Herbicides: Broadleaf Weed Control Ratings (cont.)

[a]These herbicides do not control triazine-resistant biotypes of pigweed, waterhemp, lambsquarters, or kochia.
[b]May also control some grass species. See Table 15.09.
[c]ALS-resistant waterhemp (pigweed) or kochia is not controlled by these ALS herbicides.
[d]Adjuvant varies with herbicide.
[e]The response rating increases if an NIS or COC is added to the spray mix.
[f]Requires use of Liberty Link corn hybrids.
[g]Use COC or NIS, but NIS only with some tank mixes.
[h]Requires use of IMI-designated corn hybrids.
[i]Use of IR-designated corn hybrids minimizes insecticide interaction and injury potential.
[j]Use an NIS and not COC.
[k]Use Roundup Ready corn hybrids.

For herbicide ratings for tank mixes or premixes, see the component parts:

Premix	Grass	Broadleaf
Bicep II	Dual II	atrazine
Bullet	Micro-Tech	atrazine
FulTime	TopNotch	atrazine
Guardsman	Frontier	atrazine
Harness Xtra	Harness	atrazine
Surpass 100	Surpass	atrazine
Broadstrike + Dual	Dual	Python
OpTill	Frontier	Banvel

Table 15.11. Corn "Post-Grass" Herbicides: Maximum Grass Sizes in Inches

Rate/A:	Celebrity G or Accent ⅔ oz	Basis ⅓ oz	Accent Gold 2.9 oz	Basis Gold 14 oz	Beacon 0.76 oz	Liberty[a] 28 fl oz	Light -ning[b] 1.28 oz	Poast Plus[c] 24 fl oz
	Size[d]	Size[d]	Size[d]	Size[d]	Size[d]	Size[d]	Size[d]	Size[d]
Annual grasses								
Barnyardgrass	4	2	3	3	—	4	3	8
Crabgrass, large	—	—	1	1	—	4	3	6
Cupgrass, woolly	4	≤1*	1*	1	—	10	3	8
Foxtail, giant	4	2	3	3	2*	10	6	8
Foxtail, green	4	2	3	3	2*	10	3	8
Foxtail, yellow	4	2	3	2	2*	4	3	8
Panicum, fall	4	2	3	3	< 2	4	3	8
Sandbur, field	3	—	2	2	4*	3	≤1	3[e]
Shattercane	12	4*	6*	6*	12	6	8	18
Signalgrass, broadleaf	2	—	—	2	—	4	8	8
Johnsongrass, seedling	12	—	8	8	12	6	8	8
Perennial grasses or sedge								
Johnsongrass, rhizome	8 to 18	—	—	—	8 to 16	*	8*	25
Muhly, wirestem	—	—	—	—	—	*	—	6[f]
Nutsedge, yellow	—	—	2*	2*	4*	*	3*	—
Quackgrass	4 to 10	—	8*	4*	4 to 8	*	3*	8[f]
Perennial weeds								
Artichoke, Jerusalem	—	—	—	—	4	*	10	—
Thistle, Canada	—	—	4*	4*	9*	*	3*	—

— = not listed on the label.
*Suppression or reduced competition only.
[a]Use only with Liberty Link or GR (glufosinate-resistant) corn hybrids.
[b]Use only with IMI-designated corn hybrids.
[c]Use only with PP- or SR-designated corn hybrids.
[d]Height or length of laterals or tillers in inches.
[e]Requires 30 fluid ounces.
[f]Requires 36 fluid ounces.

Table 15.12. Corn "Post-Broadleaf" Herbicides: Maximum Broadleaf Weed Sizes in Inches

Herbicide (rate)	Burcucumber	Cocklebur, common	Jimsonweed	Kochia	Lambsquarters	Morningglories, annual	Nightshade, eastern black	Pigweeds	Ragweed, common	Ragweed, giant	Smartweeds	Sunflower, wild	Velvetleaf
Translocated herbicides													
2,4-D amine[c]	—	6	3*	2*	4	6	2*	4	6	6	2*	2	2
Accent	3	—	3	—	—	2–3	—	4	—	—	4	—	—
Accent Gold	—	6	6	—	2*	—	2*	4	6	6	6	6	6
Banvel/Clarity[c]	4	4	4	4	4	4	4	4	4	4	6	2	2
Basis	—	—	—	—	3	—	—	3	—	—	3	3	3
Basis Gold	—	3	4	—	3	3	2	4	3	3	4	6	3
Beacon (0.38 oz)	—	4	4	—	—	—	4	3	6	6	2	6	—
Beacon (0.76 oz)	4	4	4	4	1.5*	1.5*	4	4	9	9	4	9	4
Beacon[a,b] + 2,4-D	3	4	4	—	3	—	4	5	6	6	4	10	4
Beacon[a,b] + Banvel[b]	4	4	4	4	3	—	4	5	6	6	4	10	4
Beacon[a,b] + Accent[a]	4	4	4	—	3*	2*	4	4	6	6	4	6	4
Celebrity B	3	3	3	3	3	3	3	3	3	3	3	3	3
Exceed (1 oz)	8	12	6	6	4	4*	4	5	12	10	6	12	10
Hornet (2.4 oz)	—	6	6	2*	2*	2*	2*	2*	6	6	6	6	6
Hornet (3.2 oz)	—	8	8	4*	4*	4*	4*	4*	8	8	8	8	8
Lightning	—	8	3	3	3	3	3	8	3*	3	3	3	3
Marksman[c]	4	6	6	6	6	6	6	6	6	6	8	6	6
NorthStar (5 oz)	4	6	6	4	3	3	6	5	9	9	4	9	4
Permit (0.67 oz)	3*	9	—	3	2*	—	—	3	9	3	2	12	9
Permit (1.33 oz)	12*	14	—	6*	2*	3*	—	6	12	6	2	15	12
Permit[b] + 2,4-D	3*	12	4	3	6	6	—	12	12	3	3	12	12
Permit[b] + Banvel	12	12	4	6	6	6	6	12	12	6	3	12	12
Resolve	—	8	3	3	3	3	3	8	3	3	3	3	3
Scorpion III	—	6	6	2	6	6	2	6	6	6	6	6	6
Sencor[b] + Banvel	4	8	5	2	6	3	6	6	5	5	6	6	6
Spirit (1 oz)	6	8	6	4	3	4*	5	4	9	9	6	12	6
Contact herbicides with variable rates													
Aim	—	—	—	—	4	3L	4	4	—	—	—	—	36
Atrazine[c] 4L (2 qt)	—	4*	4	—	6	4	4	6	4	4	4	—	2*
Basagran 4S (1.5 pt)	—	6	6	—	—	—	—	—	—	—	6	5	2
Basagran 4S (2 pt)	—	10	10	—	2*	4*	—	—	3	6	10	8	5
Buctril (1 pt)	—	8	4	—	6	3	6	—	4	4	4	6	3
Buctril (2 pt)	4	10	6	2	8	4	6	2	6	6	6	8	5
Buctril + Atrazine (1.5 pt)	—	8	4	2	6	3	4	2	4	6	4	8	3
Buctril + Atrazine (3.0 pt)	4	12	6	4	12	4	6	4	6	8	8	12	6
Laddok S-12 (1.67 pt)	—	8	6	4	5	4	1	6	4	4	10	6	5
Laddok S-12 (2.33 pt)	3	8	8	4	8	6	1	6	5	6	12	8	8
Liberty (20 fl oz)	4	8	4	2	2	4	4	*	6	6	8	8	3
Liberty (28 fl oz)	8	12	8	4	4	6	6	4	12	10	12	12	5
Liberty ATZ (32 fl oz)	4	8	4	2	2	4	4	*	6	6	8	8	3
Liberty ATZ (40 fl oz)	8	12	8	4	4	6	6	4	12	10	12	12	5
Resource[d] (6 fl oz)	—	—	—	—	3L*	—	—	3L	3L*	—	—	—	6L
Resource[a,d] + atrazine	4R[d]	—	—	—	—	—	—	3L	2L	—	—	—	6L
Tough 5E[d] (1.5 pt)	4L	4L	4L	4L	4L	—	4L	4L	—	—	—	4L	—

Table 15.12. Corn "Post-Broadleaf" Herbicides: Maximum Broadleaf Weed Sizes in Inches (cont.)

* = Suppression or partial control only; — = no control or weed not on label.
[a]Half rate or low rate.
[b]Herbicide with label for tank mix.
[c]No sizes given on label; weed sizes here are best estimates.
[d]All weed sizes given in inches, except Resource and Tough use leaf number, "L" designation; for Resource + atrazine, 4R = 2–4 runners up to 10 inches long.

Table 15.13. Corn Postemergence Herbicide Tank Mixes: "Broadleaf" + "Grass" Herbicides

	ALS-Grass						ACC-ase Grass
Broadleaf	Accent	Accent Gold	Basis	Basis Gold	Beacon	Lightning	Poast Plus
PGR or ALS							
2,4-D	–/No!	–/No!	–/–	–/No!	–/Y	–/Y	–/Y
Banvel/Clarity	Y/Y	–/Y	Y/Y	–/Y	Y/Y	Y/Y	–/–
Beacon @ 0.5X	Y/$-_R$	–/–	–/No!	–/–	–/–	–/–	–/–
Contour	Y/$-_R$	–/–	–/No!	–/–	–/–	–/–	–/–
Exceed	Y/Y	–/–	–/No!	–/–	Y/$-_R$	–/–	No!/–
Hornet	Y/–	–/–	–/Y	Y/Y	–/–	–/–	–/–
Marksman	Y/Y	–/Y	–/Y	–/–	–/Y	–/–	–/–
NorthStar	Y/–	–/–	–/–	–/–	Y/$-_R$	–/–	No!/–
Permit	Y/–	–/–	–/No!	–/–	Y/–	–/–	–/–
Pursuit	Y/$-_R$	–/–	–/No!	–/–	–/–	–/–	–/–
Resolve	Y/$-_R$	–/–	–/No!	–/–	–/–	–/–	–/–
Scorpion III	–/Y	–/–	–/Y	–/–	–/–	–/–	–/–
Spirit	Y/$-_R$	–/–	–/–	–/–	Y/$-_R$	–/–	No!/–
Contact or triazine							
Aim	Y/–	–/–	Y/–	–/–	Y/–	–/–	–/–
Atrazine	–/Y	–/Y	–/Y	–/–	–/Y	–/Y	–/Y
Basagran	–/No!	–/No!	–/No!	–/No!	–/–	–/–	–/Y
Buctril	Y/Y	–/–	–/–	–/–	Y/Y	–/Y	–/–
Buctril + Atrazine	Y/Y	–/–	–/–	–/–	–/Y	–/–	–/–
Laddok S-12	–/No!	–/No!	–/No!	–/No!	–/–	–/–	Y/Y
Liberty	Y/–	–/–	–/–	–/–	Y/–	–/–	–/–
Liberty ATZ	Y/–	–/–	–/–	–/–	Y/–	–/–	–/–
Resource	Y/Y	–/–	–/–	–/–	Y/Y	–/–	–/–
Tough	Y/–	–/–	–/Y	–/Y	Y/–	–/–	–/–

Y/– = "broadleaf" label only; Y/$-_R$ = "broadleaf" label only, reduced "grass" rate; –/Y = "grass" label only; –/No! = prohibited by grass label; No!/– = prohibited by the "broadleaf" label; Y/Y = both labels; –/– = neither label.

inches in height. *Do not make more than one application per growing season of imazethapyr.*

Poast Plus 1E (sethoxydim) may be used on PP-corn hybrids (Poast Protected) at 24 fluid ounces for most annual grasses, (Table 15.11) with a higher rate allowed for larger or perennial grasses (see label).

Liberty 1.67S (glufosinate) is used in Liberty Link or GR corn hybrids at 16 to 28 fluid ounces per acre to control small annual grass and broadleaf weeds. Tank-mix with atrazine to improve broadleaf control.

Liberty ATZ 4.3L, a premix of Liberty and atrazine, is applied to field corn less than 12 inches tall at 32 to 40 fluid ounces per acre. See Tables 15.09 to 15.12 for weed ratings and sizes. A second application of Liberty (not ATZ) is allowed to control later-emerging weeds.

Table 15.14. Corn Postemergence Herbicide Tank Mixes: Broadleaf + Broadleaf Herbicides

	PGR-systemic "broadleaf"						ALS-systemic "broadleaf"					
	2,4-D	Banvel	Clarity	Marksman	Stinger	NorthStar	0.5X Beacon	Exceed	Lightning	Permit	Pursuit	Spirit
Systemic												
2,4-D	–/–	–/Y	–/Y	–/–	–/–	–/–	–/Y	–/Y	–/Y	–/Y	–/–	–/Y
Banvel	Y/–	–/–	–/–	–/–	Y/–$_{CT}$	–/Y	Y/Y	Y/Y	Y/Y	Y/Y	Y/Y	–/Y
Beacon @ 0.5X	Y/–	Y/Y	Y/Y	Y/–	–/–	–/Y	–/–	–/Y	–/–	–/Y	–/–	–/Y
Clarity	Y/–	–/–	–/–	–/–	Y/–$_{CT}$	–/Y	Y/Y	Y/Y	Y/Y	Y/Y	Y/Y	–/Y
Hornet	Y/–	Y/–	Y/–	Y/–	Y/–$_{CT}$	–/–	–/–	–/–	–/–	–/–	–/–	–/–
Marksman	–/–	–/–	–/–	–/–	Y/–$_{CT}$	–/Y	–/Y	–/Y	–/–	–/Y	–/Y	–/Y
Contact												
Aim	Y/–	Y/–	Y/–	Y/–	–/–	–/–	Y/–	Y/–	Y/–	–/–	–/–	Y/–
Basagran	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/–	–/Y	–/–
Buctril	Y/–	Y/–	Y/–	–/–	Y/–$_{CT}$	–/–	Y/Y	Y/Y	–/Y	Y/Y	Y/Y	–/Y
Buctril + atrazine	Y/–	Y/–	Y/–	–/–	Y/–$_{CT}$	–/–	–/Y	–/Y	–/–	–/Y	–/–	–/Y
Laddok S-12	Y/–	–/–	–/–	–/–	Y/–$_{CT}$	–/–	–/–	–/–	–/–	–/–	–/–	–/–
Liberty	–/–	Y/–	Y/–	Y/–	Y/–	–/–	Y/–	–/–	–/–	Y/–	–/–	Y/–
Liberty ATZ	–/–	Y/–	Y/–	–/–	Y/–	–/–	Y/–	–/–	–/–	Y/–	–/–	Y/–
Resource	Y/–	Y/–	Y/–	Y/–	Y/–	–/Y	Y/–	Y/–	–/–	Y/–	–/–	–/Y
Tough	Y/–	Y/Y	Y/–	Y/–	–/–	–/Y	Y/–	Y/Y	–/–	Y/–	–/–	–/Y
Triazines–contact												
Atrazine	–/–	–$_G$/Y	–$_G$/Y	–$_G$/Y	–/–	–/Y	–/Y	–/Y	–/Y	–/Y	–/Y	–/Y
Sencor	Y/–	Y/–	Y/–	Y/–	–/–	–/–	–/–	–/–	–/–	–/–	Y/–	–/–

	Triazine	*Other contact herbicides*			
Triazine	*Atrazine*	*Basagran*	*Buctril*	*Laddok*	*Tough*
Aim	Y/–	–/–	No/–	–/–	–/–
Atrazine	–/–	–/Y	–/Y	–/Y	–/Y
Liberty	Y/–	Y/–	Y/–	Y/–	Y/–
Liberty ATZ	Y/–	Y/–	Y/–	–/–	Y/–
Resource	Y/–	–/–	Y/–	Y/–	No!/–
Sencor	Y/–	Y/–	Y/–	Y/–	Y/Y

Y/– = "row" herbicide label (on top); –/Y = "column" herbicide label (at left); Y/Y = tank mix on both labels; Y/–$_{CT}$ = Stinger added for Canada thistle control; –$_G$/Y = atrazine added for grass control; No!/– or No/– = tank mix prohibited.

Atrazine[RUP] controls certain small (< 1.5 inches) annual grasses (Table 15.09) at 2.2 pounds of 90DF or 4 pints of 4L per acre and broadleaf weeds (Table 15.10) at 1.3 pounds of 90DF or 2.4 pints of 4L per acre. Always add 1 quart of COC per acre. *After corn emerges,* do not apply in liquid fertilizer carrier or add 2,4-D. Maximum corn size allowed is 12 inches tall. *Atrazine does not control triazine-resistant broadleaf weeds.* Best management practices and maximum rate per year for atrazine are explained in the "Soil-Applied 'Broadleaf' Herbicides (Corn)" section. Sequential applications are allowed, but do not use more than 2.5 pounds a.i. of atrazine. If atrazine is applied after June 10, plant only corn or sorghum the next year.

Table 15.15. Herbicide Label Statements: Interactions with Organophosphate (OP) Insecticides

	Soil-applied OP insecticides[a] Counter 20CR				Foliar OP insecticide[b]	
Corn herbicide	Furrow	T-Band	Thimet	Lorsban	Days before	Days after
nicosulfuron and rimsulfuron						
Accent	No	TCI[c,d]	TCI	TCI	7	3
Accent Gold	No	No	No	TCI	7	3
Basis	UCI	UCI	UCI	TCI	7	3
Basis Gold	No	TCI[c]	TCI	TCI	7	3
Celebrity B & G	No	TCI[c,d]	TCI	TCI	7	3
primisulfuron and prosulfuron						
Beacon	No	UCI[d]	TCI	TCI	10	7
Exceed	No	UCI[d]	TCI	TCI	10	7
NorthStar	No	UCI	TCI	TCI	10	7
Spirit	No	UCI[d]	TCI	TCI	10	7
flumetsulam						
Broadstrike + Dual	No[d]	No[d]	No	TCI[e]	—	—
Hornet	No[d]	No[d]	No	TCI[e]	10	10
Python	No[d]	No[d]	No	TCI[e]	—	—
Scorpion III	Is not soil applied[d]	—	—	—	7	7
imazethapyr and imazapyr						
Contour-IT[f]	Yes	Yes	Yes	TCI	—	—
Lightning-IT[f]	Yes	Yes	Yes	TCI	—	—
Pursuit-IT[f]	Yes	Yes	Yes	TCI	—	—
Resolve-IT[f]	Yes	Yes	Yes	TCI	—	—
halosulfuron						
Permit	Is not soil applied[d]					

No = Do not use this herbicide on corn if this insecticide was previously soil applied in this manner.
UCI = Using this herbicide on corn if this insecticide was previously soil applied in this manner may result in unacceptable crop injury.
TCI = Using this herbicide on corn if this insecticide was previously soil applied in this manner may result in temporary corn injury.
[a]Fortress and Aztec are soil-applied OP insecticides, but they do appear to interact with ALS herbicides.
[b]Foliar-applied OP = Cygon, Diazianon, DiSyston, Imidan, Lorsban, malathion, or Penncap-M.
[c]Herbicide label states crop injury may be unacceptable on soils with ≤ 4% organic matter content.
[d]Counter CR supplemental labeling allows its use in this manner with this herbicide!
[e]Do not place Lorsban in-furrow if Broadstrike + Dual, Hornet, or Python are to be soil applied.
[f]IT = imidazolinone-tolerant hybrids. All soil-applied insecticides can be used on IR or IMR corn hybrids.

Postemergence Broadleaf Control (Corn)

There are three herbicide modes of action used for postemergence control of broadleaf weeds in corn: plant growth regulator (PGR), acetolactate-synthase (ALS) inhibitor, and contact (triazines have post-emergence contact action). Banvel, Clarity, Stinger, and 2,4-D are systemic PGR herbicides, whereas Marksman and Shotgun are premixes of PGR plus triazine herbicides. Beacon, Exceed, Lightning, Permit, Pursuit, and Spirit are systemic ALS-inhibiting herbicides, whereas Hornet, NorthStar, Resolve, and Scorpion III are premixes of ALS plus PGR herbicides. Atrazine, bromoxynil, bromoxynil + atrazine, Laddok S-12, Resource, Sencor, and Tough are contact herbicides. *Closely observe drift precautions with all post-emergence herbicides, but drift is often more serious with systemic broadleaf herbicides.*

Systemic (Translocated) Broadleaf Herbicides (Corn)

Translocated PGR or ALS herbicides must be applied at corn growth stages specified on the label to minimize corn injury and drift potential. Directed sprays (drop nozzles) are often specified for later applications to keep the spray out of the corn whorl, maximize spray contact with weeds, and minimize drift potential. Adding an adjuvant may increase crop injury potential, but many herbicide labels allow or require the use of an adjuvant to improve activity. See Table 15.10 for broadleaf weeds controlled and Table 15.14 for tank mixes to improve broadleaf weed control. Table 15.12 indicates maximum broadleaf weed size specified for postemergence herbicides used in corn. Table 15.16 lists labeled adjuvants, minimum time between application and rainfall for optimal herbicide activity, and required reentry intervals.

Banvel or **Clarity** (dicamba) or **Marksman**RUP (dicamba + atrazine) may be applied from spike to the 5-leaf or 8-inch stage in corn. Use 1 pint of Banvel or Clarity, or 3.5 pints of Marksman, per acre except on coarse-textured soils, where the rate is ½ pint of Banvel or Clarity and 2 pints of Marksman per acre. Split applications of Banvel and Clarity are allowed if the corn size restrictions are met, but do not exceed 1.5 pints per treated acre per season.

Banvel may be applied at ½ pint per acre to corn that is 8 to 36 inches tall or 15 days before tassels emerge, whichever comes first. Use drop nozzles on corn over 8 inches tall (especially if Banvel is applied with 2,4-D) to reduce the risk of corn injury, improve spray coverage, and reduce drift. *Do not apply Banvel to corn over 24 inches tall if nearby soybeans are over 10 inches tall or have begun to bloom.* Observe all label precautions to minimize the risk of Banvel, Clarity, or Marksman drifting to nearby susceptible crop or ornamental plants. *Both Marksman and Shotgun (see the next paragraph) contain atrazine and so must meet atrazine rate restrictions and set-back restrictions to protect ground and surface water. See the "Soil-Applied 'Broadleaf' Herbicides (Corn)" section.*

ShotgunRUP **3.25L** (atrazine + 2,4-D) may be applied at 2 to 3 pints per acre to corn from spike to the 4-leaf stage (or 8 inches tall) or up to 12 inches in height if drop nozzles are used. *Do not use over 2 pints on sandy soils.* Because Shotgun contains atrazine and 2,4-D, *the label carries atrazine restrictions as well as 2,4-D protective equipment requirements.*

2,4-D amine or **2,4-D ester** may be used from emergence to tasseling of corn. Apply with drop nozzles if corn is more than 8 inches tall. The rate is ⅓ to ½ pint of 2,4-D ester or 1 pint of 2,4-D amine per acre if the acid equivalent is 3.8 pounds per gallon. *If temperatures exceed 85°F, 2,4-D ester can volatilize* and injure nearby susceptible plants. Spray particles of either 2,4-D ester or amine can drift and cause injury to susceptible plants. **Observe protective equipment requirements on the 2,4-D label.**

Corn is often brittle for 1 to 2 weeks after 2,4-D is applied and may be susceptible to stalk breakage from high winds or cultivation. Other symptoms of 2,4-D injury are stalk lodging, abnormal brace roots, and failure of leaves to unroll. Corn hybrids differ in their sensitivity to 2,4-D. High humidity and temperature increase the potential for 2,4-D injury to corn.

Hornet 85.6WG (flumetsulam + clopyralid) may be applied to field corn up to 20 inches tall or V-6 stage and **Stinger 3S** (clopyralid) or **Scorpion III 84.3WG** (flumetsulam + clopyralid + 2,4-D) up to 24 inches tall. Because Scorpion III contains 2,4-D, use drop nozzles if corn is over 8 inches tall. Rates per acre are 1.6 to 3.2 ounces (⅙ to ⅓ packet) of Hornet, ¼ to ½ pint of Stinger, or 4 ounces (½ packet) of Scorpion III. Hornet or Stinger suppresses Canada thistle, and Stinger at higher rates controls Canada thistle. See the label or Tables 15.10 and 15.12 for weeds controlled and size limits and Table 15.16 for adjuvant selection. *The interval before planting soybeans is 10.5 months after applying clopyralid.*

Spirit 57WDG and **Exceed 57WDG,** 3:1 and 1:1 premixes of primisulfuron:prosulfuron, respectively, are applied at 1 ounce (¼ packet) per acre broadcast over the top of field corn between 4 and 20 inches in height. Use drop nozzles for corn 20 to 24 (Spirit) or 30 inches (Exceed) in height or past 6 leaf collars (V-6 stage). *Exceed and Spirit have the potential to select for ALS-resistant weed biotypes.*

If rotating to soybeans the next year: Do not apply after June 30, or on soils with pH over 7.8, because of concern with prosulfuron carryover. Use Exceed below Interstate (I) 70, or if STS soybeans are grown, between I-70 and I-80. Use Spirit between I-70 and I-80 and NorthStar above I-80.

NorthStar 47.4WDG (primisulfuron + dicamba) has *the same recropping restriction as Beacon.* Apply at 5 ounces per acre over the top of corn between 4 and 20 inches tall (V-2 to V-6), or with drop nozzles up to 36 inches tall. Exceed, Spirit, and NorthStar control many annual broadleaf weeds (Tables 15.10 and 15.12), but they can also be tank-mixed with other herbicides (Tables 15.13 and 15.14). Observe corn height limits for the tank-mix partner. *Exceed, Spirit, and NorthStar labels carry precautions regarding soil insecticides use similar to the Beacon label.*

Permit 75WG (halosulfuron) may be applied from spike to the layby stage of field corn at a rate of ⅔ to

Table 15.16. Corn "Post" Herbicides: Adjuvant Use Plus Application and Use Restrictions

Herbicide	Adjuvant and nitrogen	Rain-free period (hr)	Reentry interval (hr)	PHI days	Apply over the top of corn	Use drop nozzles
2,4-D amine	None	6–8	48	7	8″	8″ to tassel
2,4-D ester	None	1–2	12	7	8″	8″ to tassel
Accent	COC or NIS[a] + NH_4	4	4	30	20″/V-6	20″ to 36″/V-10
Accent Gold	COC + NH_4	6	48	85	12″/V-6	
Aim	NIS	1	12	??	8-leaf/V-8	
Atrazine	COC	1–2	12	21	12″	
Banvel	If droughty[b], NIS or NH_4	4	24	—	24″[c] to 36″	Reduces drift
Basagran	COC + NH_4	6[d]	12	12	Any size?	
Basis	NIS or COC + NH_4	4	4	30	6″/V-2	
Basis Gold	COC + NH_4	4	12	30	12″/V-6	
Beacon	COC or NIS[a] + NH_4	4	12	45	4″ to 20″	Splits 20″ to tassel
Buctril	COC[e] or NIS[e]	1	12	30	Pretassel	
Buctril + atrazine	COC[e] or NIS[e]	1	12	30	12″	
Celebrity B & G	NIS[a] + UAN (no AMS)	4	12	—	20″/V-6	20″ to 36″/V-10
Clarity	UAN + COC[b,f] or NIS[b]	4	12	—	8″; 5″ with oil	
Contour[g]	COC or NIS + NH_4	1	12	45	12″	
Exceed	COC or NIS + NH_4	4	12	60/30	4″ to 20″	20″ to 30″
Hornet	NIS or COC + NH_4 if dry	6	48	85	20″/V-6	
Laddok S-12	COC + NH_4	6[d]	12	21	12″	
Liberty[h]	AMS only!	4	12	70/60	24″/V-7	24″ to 36″
Liberty[h] ATZ	AMS only	4	12	70/60	12″	
Lightning[g]	COC or NIS + NH_4	1	12	45	18″ ideally	
Marksman	COC[b] or NIS[b] or NH_4[b]	4	48	—	5-leaf or 8″	
NorthStar	COC[j] or NIS + NH_4	4	12	60/45	4″ to 20″/V-6	20″ to 36″
Permit	COC or NIS + UAN	4	12	30	Layby (36″)	
Poast Plus[i]	COC; NH_4 optional	1	12	60/30	Pretassel	Layby sprays
Pursuit[g]	COC or NIS + NH_4	1	12	45	See PHI.	
Resolve[g]	NIS + NH_4	1	12	45	12″	
Resource	COC + NH_4	1	12	28	2- to 10-leaf	
Roundup Ultra[k]	AMS optional	1–2	4	7/50	30″/V-8	
Scorpion III	NIS + NH_4[b]	6	48	85	8″	8″ to 24″
Sencor	NIS or NH_4	—	12	60	Pretassel	See tank-mix partner.
Shotgun	None	4	12	21	8″/4-leaf	8″ to 12″
Spirit	COC or NIS + NH_4	4	12	60	4″ to 20″/V-6	20″ to 24″
Stinger	None	6–8	12	40	24″	
Tough	None	1–2	12	68	See PHI.	
Spot treatment only						
Roundup Ultra[l]	AMS optional	1–2	4	56/14	Pretassel	
Touchdown 5[l]	NIS, AMS optional	1–2	4	90/35	See PHI.	

COC = crop oil concentrate, NIS = nonionic surfactant, NH_4 = ammonium fertilizer adjuvant (UAN or AMS), UAN = urea–ammonium nitrate (28-0-0), AMS = ammonium sulfate (spray grade 21-0-0), PHI = preharvest interval for grain harvest, shorter for silage.

[a]Use NIS only when Accent or Beacon is mixed with anything except atrazine.

[b]Allowed if arid or droughty conditions exist at application.

[c]Up to 24 inches if nearby soybeans are over 10 inches or are blooming.

Table 15.16. Corn "Post" Herbicides: Adjuvant Use Plus Application and Use Restrictions (cont.)

[d]Current label: "Rainfall soon after application may decrease the effectiveness."
[e]Adjuvants allowed if injury is acceptable.
[f]Use of oils (penetrants) may cause injury "if corn is > 5 inches tall."
[g]Use only with IMI-designated corn hybrids.
[h]Use only with Liberty Link or GR-designated corn hybrids (glufosinate-resistant).
[i]Use only with PP- or SR (sethoxydim-resistant)-corn hybrids.
[j]COC allowed only up to 12-inch-tall corn.
[k]Use only on Roundup Ready–designated corn hybrids.
[l]Use only as a spot treatment and not as an overall application in corn.

1⅓ ounces per acre. Permit controls yellow nutsedge plus several broadleaf weeds (Tables 15.10 and 15.12). Permit may be tank-mixed with other herbicides (Tables 15.13 and 15.14). *Permit has the potential to select for ALS-resistant weed biotypes.*

Contact Broadleaf Herbicides (Corn)

Contact herbicides used in corn are Aim, bromoxynil, bromoxynil + atrazine, Laddok S-12, Resource, and Tough. Sencor is a triazine but does not have the setback restrictions or corn-size limits of atrazine or cyanazine. Atrazine tank mixes or premixes must be applied before corn is 12 inches tall. Contact herbicides require thorough spray coverage, so note label specifications for spray volume and nozzle type. See Table 15.10 for broadleaf weeds controlled and Table 15.12 for maximum weed size specified on the label. Table 15.16 lists maximum corn size allowed and potential adjuvant use. Adjuvant use changes with tank mixes, weed species, and environmental conditions. Contact herbicides are much more active in warm, humid weather and much less active in cool, dry weather.

Aim 40DF (carfentrazone) is used at ⅓ ounce per acre on corn up to eight leaf collars (V-8 stage). It may be used in many tank mixes, but not with bromoxynil or 2,4-D ester. Apply with NIS only.

Buctril or **Moxy 2E** (bromoxynil) is used at 1 pint per acre after emergence or up to 1.5 pints per acre after the 4-leaf stage of corn up to tassel emergence, but while weeds are in the 3- to 8-leaf stage. Larger pigweed and velvetleaf may require the higher rate or a combination with atrazine.

Buctril + Atrazine^{RUP} or **Moxy +Atrazine**^{RUP} **3L** (bromoxynil + atrazine) is used at 1.5 to 3 pints per acre. At the higher rate, do not apply until the 4-leaf stage of corn. *Do not apply to corn over 12 inches tall.* An NIS or COC may be added, but the potential for corn injury increases.

Laddok^{RUP} **S-12 5L** (bentazon + atrazine) is used at 1.33 to 2.33 pints per acre until corn is 12 inches in height.

Tough 5E (pyridate), at 0.75 to 1.5 pints per acre, controls some small-seeded broadleaf weeds, such as kochia and pigweed (Table 15.10). Adding atrazine (1 to 2 pints) or Banvel (0.5 to 1 pint) controls more weeds. Apply when most weeds are at the 1- to 4-leaf stage.

Sencor (metribuzin) may be included in tank mixes with several postemergence corn herbicides (Table 15.14). *Do not use a COC with any tank mix.* The rate per acre is 2 to 3 ounces of Sencor 75DF.

Resource 0.86E (flumiclorac) is used primarily at 4 fluid ounces per acre, tank-mixed with atrazine, 2,4-D, or Banvel, to improve control of velvetleaf, with the tank-mix partner determining maximum corn size and adjuvant (see label). Resource alone may be used at 4 to 8 fluid ounces plus 1 to 2 pints of COC per acre, from the 2- to 10-leaf stage of field corn.

Directed Postemergence Gramoxone for Emergencies (Corn)

Gramoxone Extra^{RUP} (paraquat) may be applied after corn is 10 inches tall, as a directed spray no higher than the lower 3 inches of cornstalks. Use 12.8 fluid ounces of Gramoxone Extra in a minimum of 20 gallons of water per acre. Always add an NIS or COC. Observe all label restrictions. Direct the spray to the base of the corn plants to minimize injury to the corn while covering the weeds as much as possible. *Adjust rates for banded application.*

Corn Preharvest Treatment

Some **2,4-D** labels allow preharvest use after the hard-dough to dent stages of corn to control or suppress broadleaf weeds that may interfere with harvest. Do not use the corn for forage or fodder for 7 days after treatment. **Roundup Ultra** (glyphosate) may be used at 1 quart by air or 3 quarts per acre by ground after grain moisture is 35 percent or less. Allow at least 7 days between application and harvest.

Herbicides for Sorghum

Atrazine, Basagran, Bicep (all formulations), Buctril, Dual II, and Permit are registered for use in grain or "forage" sorghum, but see the label for grazing and harvesting restrictions. Some other corn herbicides may be used in grain sorghum (milo) but not forage sorghum. *Check the labels for the relevant information as to rates because they may be lower than those allowed in corn.*

Gramoxone ExtraRUP (paraquat) or **Roundup Ultra** (glyphosate) may be used to control existing vegetation before planting grain sorghum in reduced-tillage systems.

Dual II (metolachlor), **Frontier** (dimethenamid), or **Micro-Tech**RUP (alachlor) and their respective premixes with atrazine (**Bicep II**RUP or **Bicep Lite**RUP, **Guardsman**RUP or **LeadOff**RUP, or **Bullet**RUP) may be used *if the sorghum seed has been treated with Screen or Concep.* **Ramrod** (propachlor), alone or with atrazine, does not require a seed safener, but it may be applied preemergence only.

AtrazineRUP is soil-applied to certain soils (see the label). Apply atrazine postemergence before sorghum is 12 inches in height, at 4 pints of 4L per acre *without a COC* or at 2.4 pints per acre with a COC for broadleaf control only. Use equivalent rates of atrazine 90DF.

ShotgunRUP (atrazine + 2,4-D) or **2,4-D** alone controls broadleaf weeds in grain sorghum that is 4 to 12 inches (Shotgun) or 24 inches (2,4-D). Use drop nozzles if the sorghum is over 8 inches in height. Vapor drift of 2,4-D ester or Shotgun can occur at temperatures above 85°F.

Banvel or **Clarity** (dicamba) at 0.5 pint per acre or **Marksman**RUP (dicamba + atrazine) at 2 pints per acre may be applied to grain sorghum after the 2-leaf stage until grain sorghum is 8 inches tall. Banvel or Clarity may be applied with drop nozzles up to the 15-inch stage.

Permit (halosulfuron) may be applied at ⅔ ounce from the 2-leaf stage through layby (but prior to head emergence). Allow 30 days before grazing or harvesting forage or silage.

LaddokRUP **S-12** (bentazon + atrazine) may be used postemergence in grain or forage sorghum up to 12 inches tall. **Basagran** (bentazon) may be used up to boot stage.

Buctril or **Moxy** (bromoxynil) applied alone can be used from the 3-leaf to boot stages, but apply premixes or tank mixes with atrazine before sorghum is 12 inches in height.

Prowl (pendimethalin) or **Treflan** (trifluralin) may be applied to grain sorghum from the 4-inch stage (Prowl) or 8-inch stage (Treflan) up to the layby stage and incorporated by cultivation. Tank-mixing with atrazine is allowed until sorghum is 12 inches in height.

Roundup Ultra (glyphosate) may be applied as a *spot treatment* in grain sorghum prior to heading.

Herbicides for Soybeans

Soybeans may be injured by some herbicides; but if stands have not been significantly reduced, they usually outgrow early injury with little or no effect on yield. Significant yield decreases can result when injury occurs during the bloom to pod-fill stages. Shallow planting can increase the risk of injury from some herbicides. Always follow label instructions. Rates per acre for preplant and preemergence herbicides for typical Illinois soils are given in Table 15.17. Accurate rate selection for soil type is essential for Canopy XL, Canopy, Lexone, Lorox, Sencor, and Turbo. *Do not apply these herbicides after soybeans begin to emerge, or severe injury can result.* See Table 15.18 for some preplant and preemergence tank-mix combinations.

Consider the kinds of weeds expected when you plan a herbicide program for soybeans. See herbicide selectivity Tables 15.19, 15.21, and 15.22 for the relative weed control ratings for various weeds with different soybean herbicides.

Early Preplant Herbicides Not Incorporated (Soybeans)

Early preplant applications of herbicides are used in no-till soybeans to control existing vegetation and reduce the need for a knockdown herbicide. Most broadleaf herbicides used in early preplant application have both foliar and soil activity, so they may control small annual weeds (Table 15.5), especially if an NIS or COC is added to the spray mix. However, if weeds are over 1 to 2 inches tall, add **2,4-D, Gramoxone Extra**RUP**, Roundup Ultra,** or **Touchdown 5** to the spray mix within label guidelines to control existing vegetation (see the earlier section on "Conservation Tillage and Weed Control").

Axiom, Command 3ME, Dual, Frontier, MicroTechRUP, or **Prowl** may be applied early preplant for grass control. Application timings before planting soybeans are as follows: Axiom within 14 days, Prowl within 15 days, Command 3ME within 30 days, or Dual II, Frontier, or MicroTech within 30 days of planting if a single application is made or within 45 days if split-applied preplant plus at planting.

Canopy, Pursuit, Pursuit Plus, Scepter, Squadron, or **Steel** may be applied within 45 days; **Broadstrike +**

Table 15.17. Soybean Herbicides: Preplant or Preemergence Rates Per Acre

Herbicide (form)	Unit	1% OM sandy loam[a]	1–2% OM silt loam[b]	3–4% OM silty clay loam[c]	5–6% OM silty clay[c]
Axiom 68WSG	oz	7–13	13	13	13
Broadstrike + Dual 7.67E	pt	1.75	2.00	2.25	2.50
Broadstrike + Treflan 3.65E	pt	1.5	2.00	2.25	2.25
Canopy 75DF	oz	4.0[d]	5.0	6.0	7.0
Canopy XL 53.6DF	oz	5.1[d]	6.4	6.8	7.9
Command 3ME	pt	2.00	2.00	2.67	2.67
Detail 4.1E	qt	1.0	1.0	1.0[e,f]	1.0[e,f]
Dual II 7.8E	pt	1.5	2.0	2.5	3.0
Dual II Magnum 7.62	pt	1.0	1.33	1.67	2.0
FirstRate 84SG	oz	0.6	0.75	0.75	0.75
Frontier 6E	fl oz	16	20	28	32
Lasso 4E	qt	2.0	2.25	2.75	3.0
Lexone 75DF	lb	0.33[d]	0.50	0.66	0.66
Lorox 50DF	lb	0.75[d]	1.3	2.0[f]	3.0[f]
Micro-Tech 4ME	qt	2.0	2.25	2.75	3.0
Partner 65DF	lb	3.0	3.5	4.0	4.5
Pentagon 60DF	lb	0.90	1.25	2.50	2.50
Prowl 3.3E	pt	1.5	2.0	3.6	3.6
Pursuit 2S	fl oz	4.0	4.0	4.0	4.0
Pursuit 70DG	oz	1.44	1.44	1.44	1.44
Pursuit Plus 2.9E	pt	2.5	2.5	2.5	2.5
Python 80WDG	oz	0.80	1.00	1.25	1.33
Scepter 70DG	oz	2.8	2.8	2.8[e,f]	2.8[e,f]
Sencor 75DF	lb	No[d]	0.50	0.75	1.00
Sonalan 3E	pt	1.5	2.0	2.5	3.0
Squadron 2.3L	pt	3.0	3.0	3.0[e,f]	3.0[e,f]
Steel 2.59E	pt	3.0	3.0	3.0[e]	3.0[e]
Treflan/Tri-4 4E	pt	1.0	1.5	2.0	2.0
Tri-Scept 3S	pt	2.33	2.33	2.33[e,f]	2.33[e,f]
Turbo 8E	pt	1.25[d]	2.25	2.75	3.50

OM = percent organic matter in the soil.
[a]Characteristic of most sandy soils in Illinois.
[b]Characteristic of many Illinois soils south of Interstate 70.
[c]Characteristic of "prairie soils" in northern Illinois.
[d]May cause excess crop injury on these soils.
[e]Carryover injury to corn may occur on these soils unless IMI-designated corn hybrids are planted.
[f]May not be suitable on these soils.

Dual, Canopy XL, or **Detail** within 30 days; or **FirstRate** within 4 weeks prior to planting soybeans for broadleaf weed control.

Assure II, Fusion, Poast Plus, Prestige, and **Select** applied preplant at reduced rates can control 3- to 5-inch annual grasses. Always add a COC. These herbicides may be tank-mixed with 2,4-D to control broadleaf weeds prior to planting soybeans (see the next paragraph).

2,4-D LV Ester may be applied prior to planting *no-till soybeans.* See Table 15.05 for weeds controlled. Apply 1 pint, 3.8 pounds acid equivalent (a.e.) per gallon, 7 days before planting soybeans, or 2 pints per acre 30 days before planting soybeans. Check the label for rates of other 2,4-D formulations. To minimize potential injury, plant soybeans 1.5 to 2 inches deep, and be sure the seeds are covered with soil. *Do not use on sandy soils with less than 1 percent organic matter.*

Table 15.18. Soil-Applied Soybean Herbicides: Tank Mixes and Application Timing

"Broadleaf"/"grass" herbicide	Canopy XL	Canopy	Command	FirstRate	Lexone or Sencor	Lorox	Pursuit	Scepter
Axiom	1,2	1,2	1[a], 2	1,2	1,2	2	1,2	1,2
Command 3ME[a]	1[a], 2	1[a], 2	—	1[a], 2	1[a], 2	2	1[a], 2	1[a], 2
Dual II Magnum	1, 2	1, 2	1[a], 2	1, 2	1, 2	2	1, 2	1, 2
Frontier	1, 2	1, 2	1[a], 2	1, 2	1, 2	2	1, 2, 3[b]	1, 2, 3[b]
Lasso/Micro-Tech	1, 2	1, 2	1[a], 2	1, 2	1, 2	2	1, 2	1, 2
Prowl/Pentagon[c]	1, 2[c]	1, 2[c]	1[a], 2[c],	1, 2[c]	1, 2[c]	2[c]	1, 2[c]	1, 2[c]
Sonalan	1	1	1	1	1	—	1	1
Trifluralin	1	1	1	1	1	—	1	1

1 = preplant incorporated; 2 = preemergence; 3 = early postemergence.
[a]Command 3ME may be lightly incorporated, but preemergence is preferred.
[b]Early postemergence, before first-trifoliate-leaf stage of soybeans.
[c]Use preemergence in Illinois soybeans only south of Interstate 80.

Table 15.19. Soybean Herbicides (Soil- or Foliar-Applied): Grass and Nutsedge Control Ratings

	Annuals								Perennials				Volunteer crops		
Herbicide	Barnyardgrass	Crabgrass	Cupgrass, woolly	Foxtail, giant	Foxtail, yellow	Panicum, fall	Sandbur	Shattercane	Johnsongrass	Muhly, wirestem	Nutsedge, yellow	Quackgrass	Cereals, volunteer (wheat, oats, rye)	Corn, volunteer	Soybean response[a]
Soil-applied[b]															
Axiom	**8**	7	6	**8**	**8**	**8**	5	4	N	N	5	N	N	N	1
Dual II	**9**	**9**	7	**9**	**9**	**9**	6	5	N	N	7	N	N	N	1
Frontier	**9**	**9**	7	**9**	**9**	**9**	5	5	N	N	7	N	N	N	1
Micro-Tech	**9**	**9**	7	**9**	**9**	**9**	6	5	N	N	7	N	N	N	1
Command 3ME	**9**	**8**	7	**9**	**8+**	**9**	**8**	7	N	N	N	N	**9**	5	1
Prowl, Pentagon	**9**	**9**	**8+**	**9**	**9**	**9**	**8**	7	N	N	N	N	6	4	1+
Sonalan	**9**	**8**	**8**	**9**	**9**	**9**	**8**	7	N	N	N	N	5	4	2
Trifluralin	**9**	**9**	**8+**	**9**	**9**	**9**	**8**	**8**	N	N	N	N	6	5	1+
Postemergence	*See Table 15.20 for maximum grass sizes*														
Assure II	**8+**	**8**	**8**	**9**	**8**	**9**	**9**	**9**	**9**	7	N	**8+**	**9**	**9**	0
Fusilade DX	**8**	**8**	**8**	**8**	**8**	**8**	**8**	**9**	**9**	**9**	N	**8+**	**9**	**9**	0
Fusion	**9**	**8**	**8**	**9**	**9**	**9**	**8**	**9**	**9**	7	N	**8**	**9**	**9**	0
Liberty	7	**8**	**8**	**8+**	7	7	7	**8**	6	7	5	5	7	**8**	1+
Matador	**8+**	**8**	**8**	**9**	**8**	**9**	**9**	**9**	**9**	7	N	**8+**	**9**	**9**	0
Poast Plus	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**8**	7	7	N	7	7	**8**	0
Prestige	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**8**	7	7	N	7	7	**8**	0
Select	**9**	**9**	**9**	**9**	**9**	**9**	6	**9**	**9**	**8**	N	**8**	**8**	**9**	0
Pursuit[b]	7	7	5	**8**	7	7	7	**8+**	5	N	5	N	N	5	1+
Raptor[b]	**8**	7	5	**8+**	**8**	**8**	**9**	**9**	6	N	5	N	6	**8**	2
Roundup Ultra[b,c]	**9**	**9**	**8+**	**9**	**9**	**9**		**9**	**9**	**8+**	7	**8+**	**9**	**9**	0

Control ratings: 9 = excellent, 8 = good, 7 = fair, 6 = poor, 5 or 4 = unsatisfactory, N = Nil or None. Boldface indicates acceptable control.
[a]Soybean response: 0 = minimal, 1 = possible, 2 = probable, 3 = serious.
[b]These herbicides also control some broadleaf weeds. See Table 15.21.
[c]Use only with Roundup Ready (glyphosate-resistant) soybean varieties.

Table 15.20. Soybean "Post" Translocated Grass Herbicides: Maximum Grass Sizes and Rates

Weed	Assure II or Matador		Fusion		Poast Plus or Prestige		Raptor 5 fl oz	Roundup Ultra[a]		Select	
	Size[b]	fl oz[c]	Size[b]	fl oz[c]	Size[b]	fl oz	Size	Size[b]	fl oz	Size[b]	fl oz[c]
Annuals											
Barnyardgrass	6	8[d]	4	8–10	4	18	5	5[e]/9	24	4	4
					8	24		7[e]/12	32	8	6–8
					12	36_R					
Brome, downy	—	—	6	6–8	—	—	—	6	12	6	6–8
Crabgrass[b]	6	8[d]	4	8–10	6	24	4*	18	24	3	4–5
					8	36_R				6	6–8
Cupgrass[b], woolly	4	9[d]	4	8–10	8	24	4*	12	24	8	6–8
			16	12–14[d]							
Foxtail, giant	4	5	8	7–10	4	18	6	12[e]/20	24	4	4
	8	7	16	12–14[d]	8	24		20	32	12	6–8
					16	36_R					
Foxtail, yellow	4	7[d]	4	8–10	8	24	6	12[e]/20	24	8	6–8
					16	36_R		20	32		
Johnsongrass, seedling	8	5	8	6–8	8	24	8	18	24	10	6–8
Panicum, fall	6	7–8	6	8–10	4	18	6	6[e]/12	24	4	4
					8	24		8[e]/18	32	8	6–8
					12	36_R					
Sandbur[b], field	6	7–8	4	8–10	3	30	—	12	12	6	6–8
Shattercane	12	5	12	6–8	18	24	8	18	24	18	6–8
Signalgrass, broadleaf	6	8[d]	4	8–12	8	24	5	5	24	4	5
					12	36_R		7	32	6	6–8
Volunteer corn	18	5	24	6–8	12	18	8	12	16	12	4–6
					20	24		20	24	24	6–8
Wheat[f], rye	6	7–8	6	8–10	4	36	4	30[e]/18+	24	6	6–8
Wheat, overwintered	—	—	—	—	—	—	—	18	24	—	—
Rhizome perennial grass:	*Minimum-maximum sizes*										
Johnsongrass, 1st	10–24	10	8–18	12	15–20	24	6–12	12–24	32–64	12–24	8–16
2nd	6–10	7	6–12	8	6–12	24	—			6–18	6–8
Muhly, wirestem, 1st	4–8	8[d]	4–12	8	6	36	—	> 8	32–64	4–8	8–16
2nd	4–8	7	4–12	8	6	36	—			4–8	8–16
Quackgrass, 1st	6–10	10[d]	6–10	12	6–8	36	4–8	6–8	32–64	4–12	8–16
2nd	4–8	7	≤ 10	8	6–8	24				4–12	8–16

NOTE: For Poast Plus or Prestige 36_R = high rate for rescue operations.
*Suppression only.
[a]Use only with Roundup Ready–designated soybean varieties.
[b]Height of grass or length of lateral growth (crabgrass, sandbur) or diameter (cupgrass), in inches.
[c]Use higher rate if tank-mixed with broadleaf herbicide, if weeds are droughty or have reached maximum size.
[d]For best results on these grasses, do not tank-mix with a broadleaf herbicide.
[e]Size is for area south of Interstate 70 in Illinois.
[f]Volunteer wheat not overwintered, such as in double-cropped soybeans.

Table 15.21. Soil-Applied Soybean Herbicides: Broadleaf Weed Control Ratings

Herbicide	Burcucumber	Cocklebur, common	Jimsonweed	Kochia	Lambsquarters	Morningglories, annual	Nightshade, eastern black	Pigweeds	Ragweed, common	Ragweed, giant	Sida, prickly	Smartweeds	Sunflower, wild	Velvetleaf	Soybean response[a]
Soil-applied "grass"															
Axiom	N	N	4	N	6	N	6	8	5	N	N	4	N	N	1
Dual II Magnum	N	N	4	N	6	N	7	8	5	N	N	N	N	N	1
Frontier	N	N	4	N	6	N	7	8	5	N	N	N	N	N	1
Micro-Tech	N	N	4	N	6	N	7	8	5	N	N	N	N	N	1
Prowl/Pentagon	N	N	N	8	9	N	N	9	N	N	N	4	N	4	1+
Sonalan	N	N	N	8	8	N	6	9	N	N	N	4	N	N	2
Trifluralin	N	N	N	8	9	N	N	9	N	N	N	4	N	N	1+
Soil-applied "broadleaf"															
Command	N	6	8	8+	8+	N	5	4	7	5	8+	8	4	9	1
Sencor/Lexone	N	6	7	8*	9*	N	N	9*	8	5	8	9	6	8	2
Lorox	N	6	6	7*	9*	N	5	9*	8	5	6	8	5	6	2
Canopy	7	9	9	8*	9*	8	5	9*	8+	8	9	9	8	8	2
Canopy XL	6	8+	8+	8+	9	8+	8+	9	8+	8	8	9	8	8	1+
Authority First	—	6	8	8	9	8	8	8+	6	6	8	7	6	6	1+
Python*	N	7	7	8	8+	5	8	9	8	5	7	8	8	8	1
FirstRate	—	8+	8+	8	8+	8	5	8+	9	8	7	8	9	8	1
Pursuit	5	7	7	8	8	7	8+	9	7	6	8	8+	8	8	1
Scepter	7	9	8	5	9	7	8	9	8+	8	8+	8+	9	7	1

Control ratings: 9 = excellent, 8 = good, 7 = fair, 6 = poor, 5 or 4 = unsatisfactory, N = Nil or None. Boldface indicates acceptable control.
[a]Soybean response: 0 = minimal, 1 = possible, 2 = probable, 3 = serious.
*Control is much less on triazine-resistant biotypes of pigweed, lambsquarters, and kochia.

For herbicide ratings for tank mixes or premixes, see the component parts:

Premix	Grass	Broadleaf
Broadstrike + Dual	Dual	Python
Broadstrike + Treflan	Trifluralin	Python
Detail	Frontier	Scepter
Pursuit Plus	Prowl	Pursuit
Squadron	Prowl	Scepter
Steel	Prowl	Pursuit + Scepter
Tri-Scept	Trifluralin	Scepter
Turbo	Dual	Sencor

2,4-D may be mixed with most other early preplant herbicides.

Soil-Applied "Grass" Herbicides (Soybeans)

Sonalan and trifluralin are soil-applied "grass" herbicides that require mechanical incorporation. Command 3ME is used primarily preemergence, whereas Dual, Frontier, Lasso, Pentagon, or Prowl may be used preplant-incorporated or preemergence. *Do not apply Pentagon or Prowl preemergence north of Interstate 80 in Illinois.* Incorporation improves herbicide performance if rainfall is limited. For more information, see the section titled "Herbicide Incorporation" and Tables 15.19 and 15.21 for the weeds controlled.

Pentagon or **Prowl, Sonalan,** and **trifluralin** are dinitroaniline (DNA) herbicides that control annual grasses, pigweeds, and lambsquarters. Control of ad-

Table 15.22. "Post-Broadleaf" Soybean Herbicides: Weed Control Ratings

Herbicide	Burcucumber	Cocklebur, common	Jimsonweed	Kochia	Lambsquarters	Morningglories, annual	Nightshade, eastern black	Pigweeds	Ragweed, common	Ragweed, giant	Sida, prickly	Smartweeds	Sunflower, wild	Velvetleaf	Soybean response[a]
Contact-postemergence						*See Table 23 for maximum weed sizes*									
Basagran	N	9	9	7	7	5	N	4	7	7	8	9	8+	8+	0
Galaxy	5	9	9	7	7	6	6	8	8	7	7	9	8	8	1+
Storm	6	8	9	6	6	7	7	9	8+	7	7	9	7	7	2
Blazer	7	7	9	6	5	8	8+	9	8+	7	N	8+	6	6	2
Cobra	7	8	9	6	6	8	8+	9	9	8+	6	7	8	7	2+
Reflex	6	7	9	5	5	7	7	9	8	7	N	8	7	6	1+
Flexstar	7	8	9	6	6	8	8	9	8+	8+	N	8+	7	7	2
Resource	5	7	7	4	7	5	4	7	7	6	7	5	4	9	1+
Stellar	7	8	8	5	7	7	8	9	8+	7	7	6	6	9	2
Liberty	7	9	9	8+	8	8	8+	8	8+	8	7	8+	9	8	1+
Systemic-postemergence						*See Table 23 for maximum weed sizes*									
Classic[ALS]	8	9	8 +	4[b]	N	7	N	8+[b]	8	7	N	8	9	8	1+
Pinnacle[ALS]	N	6	5	7[b]	8+	4	N	9[b]	5	4	N	8+	6	8	2+
Skirmish[ALS]	8	9	8+	4[b]	N	7	N	8+[b]	8	7	N	8	9	8	1+
FirstRate[ALS]	—	9	9	4[b]	N	8	N	5[b]	9	9	4	8+	9	8+	1
Synchrony STS[ALS, c]	8	9	8+	7[b]	8+	7	N	9[b]	8	7	N	9	9	8+	0
Pursuit[ALS]	5	8+	8	8[b]	6	7	9	9[b]	7	7	6	8	8	8+	1+
Raptor[ALS]	—	8+	8	8+[b]	8	7	9	9[b]	7	8	6	8	9	8+	2
Scepter[ALS]	N	9	4	4[b]	N	N	5	9[b]	5	N	N	6	7	N	1
Roundup Ultra[d]	8	9	9	8+	8	7	8[b]	9	8+	8+	6	8[b]	8+	8	0

Control ratings: **9** = excellent, **8** = good, 7 = fair, 6 = poor, 5 or 4 = unsatisfactory, N = Nil or None. — = not on label. Boldface indicates acceptable control.

[ALS]acetolactate synthase herbicides.

[a]Soybean response: 0 = minimal, 1 = possible, 2 = probable, 3 = serious.

[b]Will not control ALS (acetolactate synthase)-resistant waterhemp or kochia.

[c]Use only with STS-designated soybean varieties.

[d]Use only with Roundup Ready–designated soybean varieties. Control varies with rate and weed size.

ditional broadleaf weeds requires tank mixes (see Table 15.18) or sequential treatments with other herbicides.

If injured by DNA herbicides, soybeans show symptoms of stunting, swollen hypocotyls, and short, swollen lateral roots. Such injuries are rarely serious. If incorporation is shallow, or if Pentagon or Prowl is applied to the soil surface, soybean stems may be calloused and brittle, which can lead to lodging or stem breakage.

DNA herbicides can sometimes injure rotational crops of corn or sorghum. Symptoms appear as reduced stands and stunted, purple plants with poor root systems. Under good growing conditions, corn typically recovers from this early season injury. Accurate, uniform incorporation is needed to minimize potential carryover.

Pentagon 60DG or **Prowl 3.3E** (pendimethalin) may be applied preplant incorporated up to 15 days before planting soybeans, but incorporate within 7 days of application. Use 1.2 to 3.6 pints of Prowl or 0.85 to 2.5 lbs of Pentagon per acre. Preplant surface applications can be made 15 to 45 days (depends on tank mix or sequential) prior to planting soybeans. South of Interstate 80 in Illinois, preemergence applications may be made up to 2 days after planting. *Do not make preemergence applications north of Interstate 80.*

Treflan or **Tri-4 4E** (trifluralin) may be applied alone anytime in the spring prior to planting. However, the labels for tank mixes may specify application closer to soybean planting. Incorporate trifluralin 2 to 3 inches deep within 24 hours after application. If the soil is warm and moist, it may be beneficial to incorporate sooner. The rate per acre is 1 to 2 pints of 4E or equivalent rates of Treflan 10G. A slightly higher rate and deeper incorporation may be specified for shattercane control.

Sonalan 3E (ethalfluralin) may be applied at 1.5 to 3 pints per acre within 3 weeks before planting and should be incorporated within 2 days after applying.

Command 3ME (clomazone) is used primarily preemergence and early preplant at 1.22 to 2.66 pints per acre to control annual grasses and some broadleaf weeds. This formulation is microencapsulated to reduce volatility. *Consult the label for recommendations to minimize spray drift.* See the label or Table 15.02b for minimum recropping intervals. Carryover injury appears as whitened or bleached plants after emergence.

Axiom (FOE-5043 + metribuzin), **Dual** (metolachlor), **Frontier** (dimethenamid), or **Micro-Tech**^RUP (alachlor) may be applied up to 30 days preplant incorporated or preemergence to control annual grasses and pigweeds. Incorporate to improve yellow nutsedge control. Rates per acre are 7 to 13 ounces of Axiom, 1.5 to 3 pints of Dual II, 1.5 to 2 pints of Dual II Magnum, 20 to 32 fluid ounces of Frontier 6E, and 2 to 4 quarts of Micro-Tech. See Table 15.17 or the label for rate selection for soil type.

Soil-Applied "Broadleaf" Herbicides (Soybeans)

Broadstrike (plus Dual or Treflan), Canopy, Canopy XL, Cobra, Command, FirstRate, Lexone, Lorox, Pursuit, Python, Scepter, and Sencor are soil-applied herbicides used for broadleaf weed control in soybeans (see Table 15.21 for weeds controlled). Cobra or Lorox should not be incorporated. Broadstrike + Treflan should be incorporated, and Command 3ME may be lightly incorporated (see label). The other herbicides can be used preplant-incorporated or preemergence after planting soybeans.

Timely rainfall or incorporation is needed for uniform herbicide placement in the soil. Incorporation may improve control of deep-germinating (large-seeded) weeds, especially when soil moisture is limited. Accurate and uniform application and incorporation are essential to minimize potential soybean injury. These herbicides are meristematic inhibitors (MSI), photosynthetic inhibitors (PSI), a premix of MSI (chlorimuron) and PSI (metribuzin), or a premix of MSI (chlorimuron) plus sulfentrazone, except for Cobra and Command. **Command 3ME,** a pigment inhibitor, may be used as a broadleaf (especially velvetleaf) herbicide, but it is discussed as a grass herbicide in the preceding "Soil-Applied 'Grass' Herbicides (Soybeans)." **Cobra,** a contact postemergence herbicide, may be used preemergence at 12.5 to 19 fluid ounces per acre to control some small-seeded broadleaf weeds.

ALS Meristematic Inhibitors

Chlorimuron (in Canopy XL or Canopy), cloransulam (FirstRate), flumetsulam (Broadstrike or Python), imazaquin (Scepter), and imazethapyr (Pursuit) are meristematic inhibitors that inhibit the acetolactate-synthase (ALS) enzyme. See Table 15.21 for weeds controlled. Symptoms of ALS herbicide injury include a temporary yellowing of upper leaves (golden tops) and shortened internodes of soybeans. Although plants may be stunted, yield generally is not affected. Some of these ALS herbicides may carry over and injure certain sensitive follow crops. Symptoms on corn or grain sorghum are stunted growth, inhibited roots, and interveinal chlorosis or purpling of leaves. Symptoms on small grains are stunted top growth and excess tillering. *ALS herbicides, if used alone, increase selection pressure for ALS-resistant weed biotypes.*

Pursuit (imazethapyr) is used at 4 fluid ounces 2S per acre (1 gallon per 32 acres) or 1.44 ounces (½ soluble bag) 70DG per acre to control broadleaf weeds (Table 15.21). Grass control is improved by tank-mixing Pursuit with a grass herbicide (Table 15.18). **Pursuit Plus** is a premix of Pursuit and Prowl used at 2.5 pints per acre. **Steel,** a premix of Pursuit Plus and a half-rate Scepter, is used at 3 pints per acre for improved cocklebur control. Pursuit and Pursuit Plus or Steel may be applied up to 45 days prior to planting soybeans. If sufficient rain does not occur before planting, then incorporate mechanically. *South of Interstate 80,* Pursuit Plus and Steel may be surface-applied up to 2 days after soybean planting. See the label or Table 15.02b for minimum recropping intervals. Pursuit controls velvetleaf better than Scepter does, but Scepter provides better control of cocklebur.

Scepter 70DG (imazaquin) is used at 2.8 ounces (½ soluble bag) per acre. Preplant applications (surface or incorporated) may be made up to 45 days before planting (fewer days with many tank mixes). Scepter controls many broadleaf weeds (Table 15.21). Incorporation decreases dependency on rainfall and may improve control of velvetleaf and giant ragweed. Grass control is improved by mixing with "grass" herbicides (Table 15.18).

Detail, Squadron, and **Tri-Scept** are premixes of Scepter plus Frontier, Prowl, or trifluralin, respectively. The rate per acre is 1 quart of Detail, 3 pints of Squadron, or 2.33 pints of Tri-Scept (see Table 15.04 for equivalents). Tri-Scept must be incorporated within 24 hours, with incorporation optional for Detail and Squadron.

A line through Peoria, extending west along Illinois Route 116 and east along U.S. Route 24, delineates Detail, Scepter, Squadron, Steel, and Tri-Scept rotational crop restrictions in Illinois (Table 15.02b). Region 3 is north of the line; Region 2 is south. The potential for carryover is greater on soils with high organic matter and low pH. Research and field results indicate that, in Illinois, imazaquin is best adapted to the soils and weeds south of Interstate 70.

Significant problems have occurred in Illinois with carryover of imazaquin associated with soil and climatic conditions plus lack of uniformity in application. Reduced rates, which can reduce potential carryover, are allowed for postemergence use of Scepter and in tank mixes with several other products. *Imidazolinone-tolerant or -resistant (IR/IT) hybrids may be used to minimize carryover problems in corn.*

Broadstrike + Dual 7.67E (flumetsulam + metolachlor) may be applied at 1.75 to 2.5 pints per acre up to 14 days prior to or immediately after planting soybeans. **Broadstrike + Treflan 3.65E** (flumetsulam + trifluralin) is applied at 1.5 to 2.25 pints per acre up to 30 days prior to planting soybeans. Uniformly incorporate into the top 2 to 3 inches of soil within 24 hours after application. **Python 80WDG** (flumetsulam) at 0.8 to 1.33 ounces per acre may be applied preplant incorporated or preemergence.

FirstRate 84SG (cloransulam) may be used at 0.6 to 0.75 ounces per acre up to 4 weeks preplant (surface or incorporated) or preemergence up to 2 days after planting. Tank mixes with "grass" herbicides are allowed (see Table 15.18).

Canopy 75DF (metribuzin + chlorimuron) is applied preplant incorporated or preemergence at 4 to 7 ounces per acre. *Do not apply Canopy after soybean emergence. Do not apply Canopy to soils with pH greater than 6.8.* High soil pH may occur in localized areas. Correct rate selection for the soil and uniform, accurate application and incorporation are essential to minimize soybean injury and potential follow-crop injury. *Check labels carefully for rotational guidelines.*

Canopy XL 56.3DF (5:1 sulfentrazone:chlorimuron) is applied early preplant, preplant incorporated, or preemergence at 5.1 to 7.9 ounces per acre. It may be tank-mixed with grass herbicides (see Table 15.18). *Do not apply to soils classified as sands with less than 1 percent organic matter or to soils with greater than pH 6.8, and do not apply after soybeans emerge.* **Authority First 75DG** (sulfentrazone) is sold as a prepack with Synchrony STS for soil application at 4 ounces per acre to control black nightshade and ALS-resistant waterhemp. See Table 15.02b for recropping intervals.

Photosynthetic Inhibitors

Linuron (Lorox) and metribuzin (Sencor or Lexone, in Canopy and Turbo) are photosynthetic inhibitors (PSI), which can cause severe soybean injury from foliar application. *Do not apply them after soybeans emerge.* They occasionally injure soybeans from soil uptake. PSI herbicide injury symptoms are chlorosis (yellowing) of the leaf margins and necrosis (dying) of the lower soybean leaves, usually appearing at about the first-trifoliate stage. Atrazine carryover or soil pH over 7.0 can intensify these symptoms. Soybeans usually recover from moderate early injury. Soybean varieties can differ in their sensitivity to metribuzin.

Sencor or **Lexone** (metribuzin) may be applied anytime within 14 days before planting soybeans. Tank mixes to control annual grasses are shown in Table 15.18. Turbo 8E contains metolachlor (Dual) to control annual grasses. Metribuzin rates are adjusted for soil type (Table 15.17). *Do not apply to sandy soil that is low in organic matter. Do not use on soils with pH greater than 7.5.*

Lorox (linuron) is best suited to silt loam soils that contain 1 to 3 percent organic matter, where the rate per acre is 1 to 1⅔ pounds of 50DF. *Do not incorporate or apply after the crop emerges.*

Postemergence Herbicides (Soybeans)

Postemergence (foliar) herbicides are most effective when used in a planned program with timely application. Foliar treatments allow the user to identify the problem weed species and choose the most effective herbicide. See Tables 15.19 and 15.22 for weed control ratings with various soybean herbicides.

Rates and timing for foliar treatments are based on weed size. Early application, when weeds are young, may allow the use of lower herbicide rates. Treatment of oversized weeds may suppress growth only temporarily, and regrowth may occur. A cultivation 7 to 14 days after application but before regrowth can often improve weed control. However, cultivation during or within 7 days of a foliar application may cause erratic weed control. Tables 15.20 and 15.23 give the soybean herbicide rate for labeled weed sizes. Tables 15.24 and 15.25 give tank mixes labeled for postemergence weed control in soybeans.

A COC or NIS is usually added to the spray mix to improve the effectiveness of the postemergence herbicide. Fertilizer adjuvants such as 28-0-0 (urea-ammonium nitrate) or ammonium sulfate (AMS) may be

Table 15.23. Soybean "Post-Broadleaf" Herbicides: Maximum Weed Sizes and Application Rates

Herbicide	Rate	Cocklebur, common	Jimsonweed	Lambsquarters[a]	Morningglories, annual (tall and ivyleaf)	Nightshade, eastern black	Pigweeds	Ragweed, common	Ragweed, giant	Sida, prickly	Smartweeds	Sunflower, wild	Velvetleaf
ALS translocated[b]	*oz/A*	*Label weed height in inches*											
Classic/Skirmish 25DF	0.50	6	4	—	2[c]	—	2[d]	—	—	—	2	5	—
Classic/Skirmish 25DF	0.75	12	6	—	4[c]	—	4[d]	4	6	—	4	8	6
FirstRate 84WDG	0.30	10	4	—	6	—	—	10	10	—	6	12	6
Pinnacle 25DF	0.25	6[c]	4[c]	4	—	—	8	—	—	—	6	6[c]	6
Pursuit 70DG	1.44[e]	8	3	2[c]	2	3	8	3	3	—	3	3	3
Raptor 1S fl oz	4–5	8	6	5	4[c]	5	8	5[c]	5	4[c]	5	8	8
Scepter 70DF	1.40	8	—	—	—	—	4	—	—	—	—	4	—
Scepter O.T. fl oz	16.0	6	—	—	2	—	4	—	—	3[c]	2	4	—
Synchrony STS	0.50	8	5	4	3[c]	—	8	4	4[c]	—	8	8	8
Other translocated													
Roundup Ultra fl oz	24	18	—	8	2	12	18	6[f]–12	4	2	6	18	3[f]–6
Roundup Ultra fl oz	32	24	6	12	4	12+	24	8[f]–18	6	3	8	18+	4[f]–12
Contact	*pt/A*	*Label weed height in inches*											
Basagran	1.0	4	4	1[c]	—	—	—	—	—	—	4	3	2
Basagran	2.0	10	10	2[c]	4[c]	—	—	3	6	4	10	8	6
Blazer, Status	1.0	—	4	—	2	< 2	< 4	2	< 2	—	4	—	—
Blazer, Status	1.5	2[c]	6	2[c]	4	2	4	3	3	—	6	—	—
Galaxy	2.0	6	6	2[c]	2[c]	< 2	2	3	6	3	6	5	5
Storm	1.5	6	6	2[c]	2	2	3	3	6	2	6	—	2
Liberty	1.25	8	4	2	4	4	2	6	6	4	8	8	3
Liberty	1.75	12	8	4	6	6	4	12	10	6	12	12	5
Contact	*pt/A*	*Label weed height in leaf stage (number)*											
Cobra	0.5	4L	4L	—	—	4L	6L	6L	4L	—	—	—	—
Cobra	0.67	6L	4L	—	2L	6L	6L	8L	6L	4L	4L[c]	2L	4L
Flexstar HL	1.25	6L	8L	2L[c]	4L	6L	6L	6L	6L	2L	6L	2L	4L
Reflex	1.25	2L	6L	2L[c]	2L	4L	4L	4L	4L	—	4L	—	2L
Resource	0.25	—	—	—	—	—	3L[c]	2L[c]	—	2L[c]	—	—	6L
Resource	0.50	3L[c]	4L	3L[c]	—	—	4L	6L	—	4L	—	—	10L
Stellar	0.31	2L	—	2L[c]	3L[c]	3L	3L	6L	2L	3L[c]	—	—	6L
Stellar	0.44	4L	4L	2L[c]	3L[c]	4L	4L	6L	4L	3L[c]	—	—	6L

[a]Lambsquarters control is erratic with many herbicides.
[b]ALS-resistant waterhemp is not controlled by ALS herbicides.
[c]Suppression or partial control only; may need supplemental control.
[d]Redroot pigweed only; smooth pigweed and waterhemp only suppressed.
[e]Use equivalent rate of other formulations.
[f]Smaller size is used south of Interstate 70 in Illinois.

Table 15.24. Soybean Postemergence Herbicide Tank Mixes: "Broadleaf" + "Grass" Herbicides

	Assure II[a]	Fusilade DX[a]	Fusion[a]	Prestige or Poast Plus[a]	Roundup Ultra[b]	Select[a]
Basagran	–/Y	–/Y	–/Y	Y/Y	Y/–	–/Y
Blazer/Status	–/–	Y/Y	–/Y	Y/Y	Y/–	–/Y
Classic	Y/Y	Y/Y	Y/Y	Y/Y	Y/–	Y/Y
Cobra	Y/–	Y/–	–/Y	–/Y	Y/–	Y/Y
FirstRate	Y/–	–/–	Y/–	Y/–	Y/–	Y/Y
Flexstar	Y/–	Y/–	Y/Y	Y/Y	Y/–	Y/Y
Galaxy	–/–	–/–	–/Y	Y/Y	–/–	Y/Y
Liberty	–/–	Y/–	Y/–	Y/–	–/–	Y/–
Pinnacle	Y/Y	Y/–	Y/Y	No!/–	–/–	Y/–
Pursuit[c,d]	Y/–	Y/Y	Y/Y	Y/Y	Y/–	Y/Y
Raptor	Y/–	Y/–	Y/–	Y/–	–/–	Y/Y
Reflex	Y/–	Y/Y	Y/Y	Y/Y	–/–	Y/Y
Resource	–/–	–/–	–/Y	–/Y	Y/–	Y/Y
Scepter	Y/–	Y/–	Y/Y	Y/Y	–/–	Y/–
Skirmish	Y/Y	Y/Y	Y/Y	Y/Y	Y/–	Y/Y
Stellar	–/–	–/–	–/–	–/–	Y/–	Y/–
Storm	–/–	–/–	–/Y	–/–	–/–	Y/Y
Synchrony STS[e]	Y/Y	Y/–	Y/Y	Y/–	–/–	Y/Y

Y/– = tank mix on "broadleaf" label (row); No!/– = label prohibits the tank mix; –/Y = tank mix on "grass" label (column); Y/Y = tank mix on both herbicide labels; –/– = neither label allows tank mix.
[a]Check labels for special instructions, as "grass" herbicide rate may increase or sequential application may be preferable.
[b]Roundup Ultra requires Roundup Ready soybean varieties.
[c]Pursuit also controls several grass species, but it tends to antagonize "grass" herbicide's action.
[d]Label for adding low-rate "grass" herbicide with Pursuit is primarily to improve control of volunteer corn and shattercane.
[e]Use only with STS-designated soybean varieties.

Table 15.25. Soybean Postemergence Herbicide Tank Mixes: "Broadleaf" + "Broadleaf" Herbicides

	Basagran	Butyrac[a]	Classic/ Skirmish	FirstRate	Liberty	Pinnacle[a]	Pursuit	Raptor	Resource	Scepter	Synchrony[b]
Basagran	–/–	Y/Y	Y/–	–/Y	–/Y	Y/Y	Y/Y	–/–	–/Y	Y/–	–/–
Blazer	Y/Y	Y/Y	Y/Y	–/Y	–/Y	Y/–	Y/Y	–/Y	–/–	Y/–	Y/Y
Butyrac[a]	Y/Y	–/–	Y/Y	–/–	–/–	–/–	Y/–	–/–	–/–	Y/Y	–/Y
Classic/ Skirmish	–/Y	Y/Y	–/–	–/–	–/–	Y/Y	–/No	–/–	–/Y	–/–	–/Y
Cobra[a]	Y/–	Y/–	Y/Y	–/–	–/–	Y/–	Y/Y	Y/Y	Y/Y	Y/–	Y/Y
FirstRate	Y/–	–/–	–/–	–/–	–/Y	Y/–	Y/–	–/–	–/Y	–/–	–/–
Flexstar	Y/–	Y/–	Y/–	–/–	–/Y	Y/–	Y/–	–/Y	Y/Y	Y/–	Y/–
Galaxy	–/–	Y/–	Y/–	–/–	–/Y	Y/Y	Y/Y	–/–	–/Y	Y/–	–/–
Liberty	Y/–	–/–	–/–	Y/–	–/–	Y/–	Y/–	Y/–	Y/–	Y/–	–/–
Pursuit	Y/Y	–/Y	No/–	–/Y	–/Y	Y/–	–/–	–/–	–/Y	Y/–	No/–
Reflex	Y/Y	Y/Y	Y/Y	–/Y	–/Y	Y/–	Y/Y	–/Y	Y/Y	Y/–	Y/Y
Resource	Y/–	–/–	Y/–	Y/–	–/Y	Y/–	Y/–	–/–	–/–	Y/–	–/–
Stellar	Y/–	–/–	Y/–	Y/–	–/–	Y/–	Y/–	Y/–	–/–	Y/–	Y/–
Storm	–/–	–/–	Y/–	–/–	–/Y	Y/–	–/Y	–/–	–/Y	–/–	–/–

Y/– = tank mix on label in the row (on top); –/Y = tank mix on label in the column (at left); Y/Y = tank mix on both herbicide labels; –/– = neither label allows tank mix; No/– or –/No = tank mix prohibited.
[a]Check label closely for rate and adjuvant use with this herbicide in tank mixes.
[b]Use only with STS-designated soybean varieties.

Table 15.26. Soybean "Post" Herbicides: Adjuvant Use Plus Use Restrictions

Herbicide	Adjuvants and nitrogen	Rain-free period (hr)	Reentry interval (hr)	Preharvest interval (days)	Feed/graze forage
No-till burndown					
2,4-D amine	None	6–8	48	NA	No
2,4-D ester	None	1–2	12	NA	No
Gramoxone Extra	COC or NIS	0.5	12	NA	NA
Roundup Ultra	AMS optional	1–2	4	NA	No
Touchdown 5	NIS; AMS optional	2–4	4	NA	No
Postemergence grass only					
Assure II/Matador	POC or NIS; NH_4 optional	1	12	80	No!
Fusilade DX	COC or NIS; NH_4 optional	1	12	Prebloom	No!
Fusion	COC or NIS; NH_4 optional	1	24	Prebloom	No!
Poast Plus, Prestige	COC; NH_4 optional	1	12	75	Hay?
Select	COC; UAN optional	1	12	60	No!
Postemergence broadleaf, contact					
Basagran	COC; NH_4 optional	6[a]	12	None	Yes
Blazer, Status	NIS or UAN	6[a]	48	50	No!
Cobra	COC or NIS; check humidity	0.5	12	45	No!
Flexstar HL	COC + NH_4	1	24	Prebloom	No!
Galaxy	COC or/and[b] NH_4	6[a]	48	50	No!
Liberty	None	4	12	70/Prebloom	No!
Reflex	NIS or COC[c]; NH_4 optional	1	24	Prebloom	No!
Resource	COC; NH_4 optional	1	12	60	No!
Stellar	COC[c]; NH_4 optional	1	12	60	No!
Storm	COC or NIS or NH_4	6[a]	48	50	No!
Postemergence—broadleaf, systemic					
Butyrac (2,4-DB)	None[d]	6–8	48	60	Yes/PHI
Classic/Skirmish	NIS, POC[c], or MSO[c] + NH_4	1	12	60	No!
FirstRate	NIS + NH_4 or COC	2	12	65–50% flower	Yes/14 days
Pinnacle	NIS or COC[b,c] + NH_4	1	12	60	No!
Pursuit	COC or NIS + NH_4	1	12	85	No!
Raptor	COC or NIS + NH_4	1	4	85	No!
Roundup Ultra[e,f]	AMS optional	1–2	4	7[f]/14[e]	Yes/PHI
Scepter	COC or NIS	1	12	90	No!
Scepter O.T.	NIS or COC[c]	4	48	90	No!
Synchrony STS	POC or MSO + NH_4	1	12	60	No!
Touchdown 5[f]	NIS; AMS optional	1–2	4	60/7	Yes: 7/56: wiper/spot
Harvest-aid use					
Gramoxone Extra	NIS or COC	0.5	12	NA	Yes?/15 days
Roundup Ultra	AMS optional	1–2	12	7/14[e]	> 25 days

COC = petroleum-oil concentrate (POC) or vegetable-oil concentrate (VOC), MSO = methylated seed oil (specialized VOC), NIS = nonionic surfactant, NH_4 = ammonium fertilizer adjuvant = UAN or AMS; UAN = urea–ammonium nitrate (28-0-0), AMS = ammonium sulfate (spray grade 21-0-0); PHI = preharvest interval.

[a]Current label: "Rainfall soon after application may decrease the effectiveness."

[b]Use only if droughty conditions exist at application.

[c]Penetrant adjuvant allowed but reduces crop tolerance.

[d]Some tank mixes allow NIS or COC; see the tank-mix partner's label.

[e]Use as broadcast treatment only with Roundup Ready–designated soybeans.

[f]Can be used as a spot treatment. Use NIS with wiper applications of Touchdown 5, but not with Roundup Ultra.

specified on the label to increase control of certain weed species, such as velvetleaf. Table 15.26 lists adjuvants labeled with various postemergence soybean herbicides, reentry intervals, and rain-free periods for optimal postemergence activity. Rainfall soon after application can cause poor weed control. Warm temperatures and high relative humidity greatly increase foliar herbicide activity. Weeds growing under droughty conditions are more difficult to control.

Postemergence herbicides for soybeans are either translocated (systemic) or contact in action. Translocated herbicides do not require complete spray coverage because they move to growing points (meristems) after foliar penetration. Their action is slow, and symptoms may not appear for a week after application, especially with the "post-grass" herbicides described next.

Translocated Herbicides for Control of Grass Weeds Only (Soybeans)

Assure II or Matador, Fusilade DX, Fusion, Poast Plus or Prestige, and Select all have the same mode of action (ACC-ase inhibition). They control only annual and perennial grasses in soybeans. Table 15.20 gives herbicide rates by grass weed heights. Grasses should be actively growing (not stressed or injured) and not tillering or forming seed heads. Cultivation within 5 to 7 days before or after application may decrease grass control. A COC is preferred, especially if weeds are droughty or maximum weed heights are approached. However, an NIS is allowed with Assure II, Fusion, Fusilade, or Matador (but not with Poast Plus, Prestige, or Select). See Table 15.26 for adjuvant use.

Specified spray volume per acre is 10 to 20 gallons for ground application or 3 to 5 gallons for aerial application. A 1-hour rain-free period after application is needed. Avoid drift to sensitive crops such as corn, sorghum, and wheat. Apply prebloom and at least 60 to 80 days before soybean harvest.

These herbicides do not control broadleaf weeds. Most labels allow tank-mixing with certain broadleaf herbicides (Table 15.24), but limitations are made as to rate, timing, and spray coverage. *Check the label before applying postemergence grass and broadleaf herbicide tank mixes or sequences. Control of grass weeds may be reduced, or increased rates may be specified.*

Rates vary by weed heights and species, so consult the label or Table 15.20 before applying. Rate reductions may be optional on small weeds or under ideal conditions, whereas rate increases may be needed for larger weeds. Johnsongrass or quackgrass often requires a follow-up application for control of regrowth.

Assure II or **Matador 0.88E** (quizalofop) controls annual grasses at 7 to 9 fluid ounces per acre. Add 1 percent POC or 0.25 percent NIS. Assure is weak on yellow foxtail. **Fusion 2.56E** (fluazifop + fenoxaprop) controls annual grasses at 6 to 8 fluid ounces per acre when used alone or 8 to 10 fluid ounces when tank-mixed. Add 0.5 to 1 percent COC or 0.25 to 0.5 percent NIS. **Fusilade DX 2E** (fluazifop) is applied at 6 fluid ounces per acre to control volunteer corn and shattercane. Add 1 percent COC or 0.25 percent NIS.

Poast Plus or **Prestige 1E** (sethoxydim) controls annual grasses at 24 ounces (1.5 pints) per acre. Always add 2 pints of COC per acre. **Select 2E** (clethodim) controls annual grasses at 4 to 6 fluid ounces per acre when used alone or 6 to 8 fluid ounces when tank-mixed. Add 1 percent COC to the spray mix.

Translocated Herbicides for Grass and Broadleaf Control (Soybeans)

Roundup Ultra (glyphosate) may be applied only to *"Roundup Ready"–designated soybeans* from emergence through the full flowering stage for control of a broad spectrum of grass and broadleaf weeds. Single and repeat in-crop *plus preharvest applications* are not to exceed a maximum of 3 quarts per acre per season. This 3-quart limit does not include applications made for burndown of existing vegetation prior to planting. Rates are based on weed height, but *consideration should also be given to species present* (Tables 15.19 and 15.22). The rate per acre is 2 pints on weeds 4 to 8 inches tall and 3 pints on weeds 8 to 18 inches tall. Glyphosate provides no residual control, so repeat applications may be needed. Applications should be made in 5 to 20 gallons of water per acre. AMS may be included for some situations (check label). *Exercise extreme care to minimize drift to susceptible plants.*

Roundup Ultra or **Touchdown 5** (glyphosate) may be applied through wiper applicators to control volunteer corn, shattercane, and johnsongrass. Hemp dogbane and common milkweed may also be suppressed (see Table 15.28). Weeds should be at least 6 inches taller than the soybeans. To minimize soybean injury, adjust the applicator so that the wiper contact is at least 2 inches above the soybean plants. For wiper applicators, mix a 1:2 ratio of Roundup Ultra:water or 1:4 ratio of Touchdown 5:water. *Spot treatments* may be made on a spray-to-wet basis using a 2 percent solution of Roundup Ultra or 1 percent solution of Touchdown 5 in water. Minimize spray contact with soybeans.

Pursuit (imazethapyr) and **Raptor** (imazamox), which are sometimes used to control small annual

grass (Table 15.19) and broadleaf weeds (Tables 15.22 and 15.23), are discussed in the following section.

Translocated Herbicides for Postemergence Control of Broadleaf Weeds (Soybeans)

Classic or Skirmish, FirstRate, Pinnacle, Pursuit, Raptor, and Scepter inhibit the acetolactate-synthase (ALS) enzyme. They primarily control broadleaf weeds (Table 15.22), although Pursuit and Raptor provide some grass control (Table 15.19). Table 15.23 lists herbicide rates by broadleaf weed species and heights. Weeds should be actively growing (not moisture- or temperature-stressed). Do not make applications when weeds are in the cotyledon stage. Annual weeds are best controlled when less than 3 to 5 inches tall (within 2 to 4 weeks after soybean emergence). A 1-hour rain-free period after application is adequate.

The ALS herbicides inhibit growth of new meristems, so symptoms of weed injury may not be exhibited for 3 to 7 days after application. Injury symptoms are yellowing of leaves, followed by death of the growing point. Death of leaf tissue in susceptible weeds is usually observed in 7 to 21 days. Less-susceptible plants may be suppressed, remaining green or yellow but stunted for 2 to 3 weeks.

Soybeans may show temporary leaf yellowing ("golden tops"), growth retardation (generally in the form of shortened internodes), or both symptoms, especially if soybeans are under stress. Under favorable conditions, affected soybeans may recover with only a slight reduction in height and no loss of yield.

Use a minimum spray volume of 10 gallons per acre and spray pressure of 20 to 40 psi. An NIS is usually specified at 1 to 2 pints per 100 gallons of spray. A COC may improve weed control but increase crop injury. Either a UAN or AMS may improve control of some weeds and is often specified for velvetleaf control. *Because tank-mixing these herbicides with postemergence "grass" herbicides may reduce grass control, sequential applications are often specified.* Tables 15.24 and 15.25 list labeled tank mixes. Table 15.23 provides rates of herbicides for various sizes of selected weeds. *ALS herbicides, used alone, increase the potential of selecting for ALS-resistant weed biotypes such as waterhemp and kochia;* see the earlier section on "Weed Resistance to Herbicides."

Raptor 1S (imazamox) is used at 4 to 5 fluid ounces per acre to control annual grasses (see Table 15.19) and broadleaf weeds (see Table 15.22). (See Tables 15.20 and 15.23 for weed sizes.) Common ragweed is only suppressed. Add either a COC or NIS plus an NH_4 fertilizer adjuvant. Raptor has better lambsquarters and grass control than Pursuit and has shorter persistence.

Pursuit (imazethapyr) is used at 4 fluid ounces 2S or 1.44 ounces (½ soluble bag) 70DG per acre plus a COC or NIS and a UAN or AMS. Pursuit controls some small annual grasses (Table 15.19), but tank mixes may interfere with grass control of Pursuit. Pursuit does not control ALS-resistant biotypes such as waterhemp. *Make only one application of Pursuit per year.* Applying herbicides containing chlorimuron or imazaquin the same year as Pursuit increases the potential for crop injury to soybeans and subsequent crops. Do not apply Pursuit within 85 days of soybean harvest. Recropping interval is 4 months for wheat and alfalfa, 18 months for grain sorghum or oats, and 8.5 months for field corn, except IMI-corn, which may be planted anytime (Table 15.02b).

Classic or **Skirmish 25WG** (chlorimuron) is used at 0.5 to 0.75 ounce per acre, plus an NIS or COC and NH_4 adjuvant. See Table 15.22 for weeds controlled and Table 15.23 for weed sizes. *ALS-resistant waterhemp is not controlled.* Split applications can improve control of burcucumber, giant ragweed, and annual morningglories. Do not apply chlorimuron within 60 days of harvest. *Applying chlorimuron after August 1 extends the corn recrop interval by 2 months.* Recropping intervals are 3 months for wheat; 9 months for corn; and 9 or 15 months for milo, alfalfa, and clover, depending on the rate used (Table 15.02b).

Pinnacle 25WG (thifensulfuron) is used at 0.25 ounce per acre to control lambsquarters, pigweeds, smartweeds, and velvetleaf. See Table 15.23 for weed heights. Add 1 to 2 pints of an NIS per 100 gallons. *Use a COC only if conditions are droughty.* A UAN improves velvetleaf control. Pinnacle is used at lower rates in some tank mixes to improve lambsquarters control (Table 15.25). Plant any crop 45 days after applying thifensulfuron alone; tank mixes or premixes require longer recropping intervals.

Synchrony STS 42WG (2.4:1 chlorimuron:thifensulfuron) is used on STS-designated soybean varieties at 0.5 ounce (¼ soluble bag) per acre. Use a COC or MSO plus an ammonium fertilizer adjuvant, *but consult the label when tank-mixing with Cobra or 2,4-DB.* Weed species controlled and heights are listed in Tables 15.22 and 15.23. Synchrony STS recropping intervals are 3 months for small grains and 9 for field corn (8 months for IR-corn). Recropping intervals for other crops vary with sequential Classic applications and soil pH (see the label or Table 15.02b).

FirstRate 84SG (cloransulam) is used postemergence at 0.3 ounce per acre to control several broadleaf weeds (Table 15.22) depending on size (Table 15.23). Add either an NIS or COC +/- NH_4 adjuvant. Tank mixes improve the control spectrum. See the label and Tables 15.24 and 15.25.

Scepter 70DG (imazaquin) at 1.4 ounces (¼ soluble bag) per acre plus an NIS or COC controls cocklebur, wild sunflower, non-IMI volunteer corn, and pigweed (not waterhemp). **Scepter O.T.** (imazaquin + acifluorfen) at 1 pint per acre provides improved control of annual morningglories and smartweeds. Do not apply Scepter within 90 days of soybean harvest. *Be sure to follow rotational guidelines on the label.*

Contact Herbicides for "Postemergence Control" of Broadleaf Weeds (Soybeans)

Basagran, Blazer or Status, Cobra, Flexstar, Galaxy, Liberty, Reflex, Resource, Stellar, and Storm are contact broadleaf herbicides used in soybeans, so thorough spray coverage is critical. Spray volume for ground application is 10 to 30 gallons per acre, and spray pressure should be 30 to 60 psi. Hollow-cone or flat-fan nozzles provide much better coverage than flood nozzles.

Low temperatures and humidity reduce contact herbicide activity. Injury symptoms are usually visible within a day. Soybean leaves may show contact burn under conditions of high temperature and humidity. This leaf burn is intensified by a COC. Soybeans usually recover within 2 to 3 weeks after application. A rain-free period of several hours is required for effective control with most contact herbicides except Cobra.

Apply contact herbicides 2 to 3 weeks after soybean emergence, when weeds are small and actively growing. Most contact herbicides have little soil residual activity, so do not apply too early. Larger weeds may require increased rates but still may recover and regrow. See Table 15.22 for weeds controlled and Table 15.23 for herbicide rates by weed height.

Basagran (bentazon) is used at 1 to 2 pints per acre. A UAN or AMS improves velvetleaf control. A COC is preferred if the major weed species is common ragweed or lambsquarters. Split applications can improve control of lambsquarters, giant ragweed, wild sunflower, and yellow nutsedge. **Rezult** is a 1:1 co-pack of Poast Plus and Basagran 5S.

Blazer or **Status** (acifluorfen) is used at 0.5 to 1.5 pints per acre. Split applications are allowed 15 days apart, but do not apply more than 2 pints per acre per season. *Acifluorfen may cause soybean leaf burn;* however, soybeans usually recover within 2 to 3 weeks. Velvetleaf control is improved with the use of a fertilizer adjuvant or the addition of bentazon.

Galaxy 3.67S and **Storm 4S** are 2:3 and 1:1 premixes of acifluorfen and bentazon, respectively (see Table 15.04 for equivalents). Galaxy is used at 2 pints per acre or up to 3 pints per acre for suppression of larger weeds. Storm is used at 1.5 pints per acre. **Manifest** and **Conclude** are co-pack delivery systems for Galaxy and Storm, respectively, plus 1.5 pt/A of Poast 1.5E. Labeled grass sizes are smaller than for equivalent rates of Poast or Poast Plus alone.

Reflex 2S or **Flexstar 1.88S** (fomesafen) controls broadleaf weeds at 1 to 1.25 pints per acre. Reflex may be used at 1.5 pints per acre south of I-70. Apply Flexstar or Reflex before soybeans bloom. *Fomesafen may cause soybean leaf burn;* however, soybeans usually recover within 2 to 3 weeks. Be sure applications are accurate and even to minimize possible carryover. *In Illinois, do not apply to the same field the following year.* Recropping intervals are 4 months for wheat, 10 months for corn, and 18 months for other crops, including grain sorghum.

Cobra 2E (lactofen) is applied at 4 to 12.5 fluid ounces per acre. Reduced rates are used in tank mixes to control giant ragweed, common ragweed, and waterhemp. See the Cobra label for details on adjuvant selection, which varies with relative humidity (used alone) and with the tank-mix partner. *Cobra can cause severe soybean leaf burn,* but soybeans usually recover within 2 to 3 weeks. Apply Cobra no later than 45 days before harvest.

Resource 0.86E (flumiclorac) is used in tank mixes (Table 15.25) at a rate of 4 fluid ounces per acre to improve velvetleaf control. It may also be applied alone at a rate of 4 to 12 fluid ounces per acre, the higher rate used primarily to control larger velvetleaf. When applied alone, a COC at 1 quart per acre must be included; if tank-mixed, adjuvant selection depends on the tank-mix partner. **Stellar 3.1E**, a premix of Resource and Cobra, is used at 5 to 7 fluid ounces per acre. Always add a COC or MSO. Do not apply Stellar or Resource within 60 days of harvest.

Liberty 1.67S (glufosinate) is used in Liberty Link soybean varieties at 16 to 28 fluid ounces per acre to control small annual grass and broadleaf weeds. A second application of Liberty is allowed to control later-emerging weeds. See Tables 15.19 and 15.22 for weed ratings.

Soybean Preharvest Treatments

Gramoxone Extra[RUP] (paraquat) may be used prior to soybean harvest when 65 percent of the seed pods have reached a mature brown color or when seed moisture is 30 percent or less. The rate is 12.8 fluid ounces of Gramoxone Extra per acre. The total spray volume per acre is 2 to 5 gallons for aerial application and 20 to 40 gallons for ground application. Add 1

quart of an NIS per 100 gallons of spray. Do not pasture livestock within 15 days of treatment, and remove livestock from treated fields at least 30 days before slaughter. Gramoxone is a better "harvest-aid" than Roundup.

Roundup Ultra (glyphosate) may be applied *preharvest* in soybeans after soybean pods have set and lost all green color, but do not expect fast weed drying. Allow a minimum of 7 days between application and soybean harvest. Do not graze or harvest treated crop for livestock feed within 25 days after a preharvest application. Roundup may be applied at a rate of 1 quart per acre by air or ground. Ground application at a higher rate is also allowed in non–Roundup Ready soybeans, but is usually feasible only for spot treatment of problem weeds such as perennials. *In Roundup Ready soybeans*, an application of 1 quart per acre may be made up to 14 days before harvest as long as the total in-crop and preharvest applications do not exceed 3 quarts per acre. *Do not treat non–Roundup Ready soybeans grown for seed beans* as there may be a reduction in germination or vigor.

Problem Perennial Weeds

Perennials first appear as light infestations, but if left unattended they can become serious, causing reductions in yield, grain quality, and harvesting efficiency. Perennial weed problems are increasing in Illinois due to less competition from annuals and reduced tillage. Spreading perennials reproduce from vegetative propagules, which can be spread by chisel plows or field cultivators. For tillage to be beneficial, root fragments must be left on the surface and exposed to either freezing or desiccation. Repeated tillage or mowing can deplete root food reserves and make the plants more susceptible to chemical control. Control of spreading perennials often relies on a combination of tillage to weaken the plants and the use of translocated (systemic) herbicides.

Translocated Herbicides to Control or Suppress Perennial Weeds

Translocated herbicides should be applied when "food" is moving to the roots if control of perennials is to be effective. Early in the spring, food moves up from root reserves to support vegetative growth, and herbicides provide only "top kill." *For the majority of perennials, the most effective applications are at early bud-to-bloom stage or early in fall,* when the plants are replenishing food reserves in the roots. Some of the best opportunities for perennial control are on land where no crop is to be harvested. Plants must be actively growing; do not disturb (cultivate or mow) for at least 10 days after application to allow time for the herbicide to translocate.

Fallow, CRP, and wheat-stubble land offer good opportunities to work on warm-season perennials. Because no control program is completely effective, adequate control may take several years. 2,4-D, Banvel, Roundup Ultra, and Touchdown 5 have label sections concerning their application to fallow or stubble ground, including CRP land. Crossbow use is limited to permanent grass areas such as CRP ground or permanent pastures (see Chapter 16). *Crossbow is not cleared for use before cropping or in corn or sorghum.*

Banvel may be applied on fallow ground at 1 to 4 pints per acre to control or suppress perennials. Use 2 pints per acre to control curly dock, horsenettle, and Canada thistle, and 4 pints per acre to control Jerusalem artichoke, field or hedge bindweed, hemp dogbane, swamp smartweed, and trumpet creeper. Upright perennials should be at least 8 inches tall, and vining perennials should be at or beyond the full-bloom stage. Corn or soybeans may be planted the spring after applications made the previous year. Soybean injury may occur if fewer than 30 days have elapsed per pint of Banvel applied per acre. Wheat may be planted if 20 days have elapsed per pint of Banvel. *Do not count days when the ground is frozen.*

2,4-D 3.8LVE (ester) or **2,4-D 3.8S** (amine) at 2 to 6 pints currently may be applied on fallow ground and crop stubble. Use equivalent rates of other formulations, as 2,4-D is available under many trade names and in various concentrations. Observe current guidelines for 2,4-D application. If possible, spray perennials that are actively growing at the bud-to-bloom stage. Do not disturb the treated area for at least 2 weeks after treatment. Multiple applications usually are required for satisfactory control. Perennials listed include field and hedge bindweed, Canada thistle, hemp dogbane, curly dock, and Jerusalem artichoke. *Do not plant soybeans or wheat for 3 months after applying 2,4-D at these rates.*

Roundup Ultra (2 to 4 quarts per acre) or **Touchdown 5** (1.5 to 3 quarts per acre) may be used on fallow or stubble ground to control perennial grasses and broadleaf weeds. Broadleaf weeds should be actively growing at late-bud to full-bloom stage (depending on the species; see the label). Lower rates may be specified for suppression or in tank mixes with 2,4-D or Banvel. Perennial broadleaf weeds controlled or suppressed include field bindweed, hemp dogbane, common milkweed, swamp smartweed, Canada thistle, and trumpet creeper. Perennial grasses include johnsongrass, quackgrass, and wirestem muhly. For forage species and CRP land, see the "Conservation Tillage and Weed Control" section.

Preharvest application may suppress or control some susceptible perennials, but is usually made to suppress annual weeds and minimize harvesting problems. Preharvest treatments often involve aerial application, but high-clearance ground equipment can sometimes be used in corn. Preharvest applications of "cleared" translocated herbicides are 2,4-D or Roundup Ultra for corn or wheat (see the *Illinois Agricultural Pest Management Handbook*, Chapter 3) and Roundup Ultra for soybeans. ***Postharvest treatments*** in corn, soybeans, and wheat require that the weeds regrow sufficiently to be in a susceptible stage before droughty conditions or frost occur. Postharvest treatments in wheat or oats are possible (see the preceding discussion of stubble ground) if the field is not undersown with a forage legume such as alfalfa or clover and is not double-cropped to soybeans or grain sorghum.

In-crop treatments offer fewer possibilities for perennial broadleaf control because rates are often reduced and weeds often are not in the most susceptible stages. Unfortunately, corn and soybeans are often in reproductive stages when most warm-season perennials are in the bud-to-bloom stage. *Do not apply translocated or contact herbicides to corn or soybeans during their reproductive stages.* ***Spot treatment*** with Roundup Ultra or Touchdown 5 is allowed in corn and soybeans up to reproductive stages. Currently there are more postemergence herbicides to control perennial broadleaf weeds in corn than in soybeans. See "Postemergence Broadleaf Control (Corn)."

Table 15.27. Corn "Post" Herbicides: Perennial Broadleaf Weed Control Ratings

Herbicide	Corn stage	Rate per acre	Artichoke, Jerusalem	Bindweed, field or hedge	Dogbane, hemp	Horsenettle	Milkweed, common	Milkweed, honeyvine (climbing)	Morningglory, bigroot (wild sweetpotato)	Pokeweed	Smartweed, swamp (devil's shoestring)	Thistle, Canada
2,4-D amine	8 in. to tassel[a]	1 pt	7	7	6	6	5	6	6	7	N	6
2,4-D ester	Preharvest	2 pt	8	8	6	7	7	7	7	8	6	7
Banvel	8–24 in.[a]	0.5 pt	8	8	5	7	6	6	5	7	7	8
Stinger	≤ 24 in.	0.5–0.67 pt	9	4	4	5	5	6	4	4	5	9
Accent + Banvel[b]	8–24 in.[a]	0.67 oz + 0.5 pt	7	7	7	7	7	8	5	6	6	8
Beacon	Pretassel[c]	0.76 oz	8	5	6	8	6	6	5	7	5	7
Beacon + Banvel[b]	4–24 in.[d]	0.38 oz + 0.5 pt	8	7	7	7	6	6	5	7	7	8
Exceed	4–30 in.[c]	1.00 oz	8	5	6	7	6	6	4	7	6	5
Exceed + Banvel[b]	8–24 in.[d]	1.00 oz + 0.5 pt[c]	8	7	7	8	6	6	5	8	7	8
NorthStar	4–36 in.[c]	5 oz	8	6	7	8	6	6	5	8	7	6
Spirit	4–24 in.[c]	1.00 oz	8	5	6	7	6	6	5	7	5	7
Spirit + Banvel[b]	4–24 in.[d]	1.00 oz + 0.5 pt	8	7	7	8	7	6	5	8	7	8
Lightning[e]	Pretassel	1.28 oz	8	6	4	5	5	6	4	6	6	6
Permit + Banvel[b]	8–36 in.[a]	0.67 oz + 0.5 pt	7	6	7	8	8	6	5	8	7	8
glyphosate[f]	Pretassel	1–2% solution	8	8	8	8	8	7	6	8	8	9
Roundup[g]	≤ 24 in.	1 qt/a	8	7	7	7	7	7	5	6	7	8
Liberty[h]	≤ 24 in.	1.75 pt	7	6	6	6	6	5	—	—	—	5

Control ratings: 9 = excellent, 8 = good, 7 = fair, 6 = poor, 5 or less = unsatisfactory. Boldface indicates acceptable control.
[a]Use drop nozzles; do not spray over whorl of corn.
[b]Use *only* NIS as adjuvant.
[c]Use drop nozzles with Beacon, Exceed, NorthStar, or Spirit in corn over 20 inches.
[d]Use drop nozzles if corn is over 12 inches tall.
[e]Lightning used on IMI-designated corn hybrids.
[f]Glyphosate (Roundup Ultra or Touchdown 5) used as a spot treatment in corn.
[g]Roundup Ultra used on Roundup Ready corn hybrids.
[h]Liberty used on Liberty Link or GR corn hybrids.

Table 15.27 lists translocated herbicides for control or suppression of perennial weeds in corn, and weed control ratings, as well as crop stages and rates per acre. Multiple low-rate treatments, if allowed, often are more effective than a single treatment at a high rate.

Banvel 4S may be applied at ½ pint per acre when corn is 8 to 36 inches tall or up to 15 days before tassel emergence, whichever is first. A second application of Banvel may be made after 2 weeks, up to a maximum of 1.5 pints per season. *Do not apply Banvel to corn over 24 inches tall if soybeans growing nearby are over 10 inches tall or have begun to bloom.* Use drop nozzles when applying Banvel tank-mixed with 2,4-D (0.25 pint per acre), when corn leaves prevent proper spray coverage, or when sensitive crops are growing nearby.

2,4-D amine or **LV ester** may be applied with drop nozzles to corn over 8 inches tall up to tassel stage. The rate per acre is 0.5 to 0.75 pint 3.8 LVE (low-volatile ester) or 1 to 1.5 pints 3.8S (amine) or equivalent rates of other formulations. *Do not use esters if temperatures are expected to exceed 85°F* the next few days following application. Adhere closely to all label precautions to prevent injury to nontarget plants in the area. *Banvel or 2,4-D at these rates only suppresses perennial broadleaf weeds.*

Stinger (clopyralid) at ⅓ to ⅔ pint per acre suppresses or controls 6- to 8-inch Canada thistle and up to 5-leaf Jerusalem artichoke. For spot treatments with hand-held sprayers, use a spray mix of 1 fluid ounce per 4 gallons or ⅓ pint per 25 gallons of water. Make applications before corn is 24 inches tall on a spray-to-wet basis (not runoff). **Hornet** (which contains Stinger) used postemergence at 3.2 to 4 ounces per acre controls 6- to 9-inch Jerusalem artichoke or Canada thistle.

Beacon or **Accent** controls quackgrass and johnsongrass in corn. See the "Postemergence (Foliar-Applied) Herbicides (Corn)" section for discussion and Table 15.09 for ratings. Beacon also suppresses small Jerusalem artichoke, Canada thistle, and horsenettle. **Exceed, NorthStar,** and **Spirit** (which contain Beacon) suppress small bindweed (hedge or field), Jerusalem artichoke, Canada thistle, and horsenettle. They also control seedling johnsongrass and suppress rhizome johnsongrass and quackgrass. Permit at ⅔ ounce per acre suppresses up to 6-inch pokeweed, and at 1 to 1⅓ ounces controls 4- to 12-inch yellow nutsedge and suppresses 4- to 12-inch common milkweed.

Tank mixes of Banvel, Clarity, or 2,4-D are allowed with Beacon, Exceed, Permit, or Spirit to improve suppression of several broadleaf species, including common and honeyvine (climbing) milkweed, hemp dogbane, Canada thistle, field bindweed, and common pokeweed (Table 15.27). Use only an NIS as an adjuvant in these tank mixes for perennials. Because these herbicides are primarily used to control annual weeds, timing is not always best for control of perennials. The degree of perennial control depends on the weed species, size, and susceptibility.

Basis GoldRUP or **Accent Gold** suppresses up to 2-inch yellow nutsedge, or 4-inch Canada thistle, common milkweed, hemp dogbane, and pokeweed. **Resolve, Contour**RUP**, Lightning,** or **Pursuit** may be used in IMI-designated corn to control 6- to 10-inch Jerusalem artichoke and suppress up to 3-inch yellow nutsedge or Canada thistle.

Roundup may be used on Roundup Ready corn hybrids to control or suppress perennial weeds in corn. Rates are 1.5 to 2 pints per acre, with a second application allowed as long as application is before corn is 30 inches tall or the V-8 leaf stage. Total in-crop applications are limited to 2 quarts per acre plus 1 quart allowed preharvest.

Translocated herbicides used in soybeans to suppress or control perennial weeds are ALS herbicides, Roundup, or ACC-ase "grass-only" herbicides. Pursuit, Classic, Synchrony STS, and Raptor are ALS herbicides used to control broadleaf weeds and suppress some perennials (Table 15.28).

Pursuit or **Raptor** controls up to 8-inch Jerusalem artichoke and suppresses small Canada thistle and yellow nutsedge. Raptor also suppresses small field or hedge bindweed.

Classic or **Skirmish** at ¾ ounce or **Synchrony STS** (only in STS-soybeans) at 0.5 ounce per acre controls 2- to 4-inch yellow nutsedge and suppresses up to 6-inch Jerusalem artichoke and 4-inch Canada thistle. Synchrony STS also suppresses up to 6-inch common milkweed or pokeweed plus 6-inch-diameter perennial sow thistle or 8-inch-diameter dandelion.

Roundup Ultra or **Touchdown 5** ***spot treatment*** may be used to control perennials (Tables 15.27 and 15.28) in corn and soybeans up to the reproductive stages of the crops. Use a 3 to 5 percent solution for low coverage and 1 to 2 percent if application is spray-to-wet (complete coverage). Fallow ground and preharvest uses are discussed earlier. ***Wiper applicators*** allow Roundup Ultra or Touchdown 5 treatment in soybeans to control or suppress perennial weeds such as johnsongrass, Jerusalem artichoke, milkweed, or hemp dogbane growing 6 inches taller than soybeans; see "Translocated Herbicides for Grass and Broadleaf Control (Soybeans)."

Table 15.28. Soybean "Post" Herbicides for Partial Control or Suppression of Perennial Weeds

Herbicide	Artichoke, Jerusalem	Bindweed, field or hedge	Dock, curly	Dogbane, hemp	Horsenettle	Milkweed, common	Milkweed, honeyvine (climbing)	Morningglory, bigroot	Nutsedge, yellow	Pokeweed	Smartweed, swamp	Thistle, Canada
Roundup Ultra[a] 1 qt	**8**	7	6	7	7	7	7	5	6	**8**	7	**8**
glyphosate[b] 1–2%	**8**[c]	**8**	7[c]	**8**	**8**[c]	**8**[c]	7	6	7	**9**[c]	**8**[c]	**9**
Classic/Skirmish[d]	7	7	6	—	5	6	7	—	6	6	—	7
Synchrony STS[e]	7	7	6	—	5	7	7	—	6	6	—	7
Pursuit	**8**	—	6	—	7	—	—	—	6	—	—	6
Raptor	**8**	6	—	—	—	—	—	—	6	—	—	7
Basagran[d]	7	5	—	—	5	—	—	—	**8**	—	—	**8**
Blazer[f]	6	6	—	—	6	6	—	5	—	—	—	6
Cobra[g]	6	6	—	—	6	6	—	6	—	—	6	6
Flexstar[h], Reflex	6	6	—	—	6	—	6	—	5	—	—	6
Liberty[i]	7	7	5	6	—	6	6	—	5	—	5	5

Control ratings: **9** = excellent, **8** = good, 7 = fair, 6 = poor, 5 or less = unsatisfactory. Boldface indicates acceptable control.
[a]Use only with Roundup Ready–designated soybean varieties.
[b]Spot treatment with 1% Touchdown 5 or 2% Roundup Ultra on a spray-to-wet basis before bloom stage.
[c]A ropewick applicator with a mix of 20% Touchdown 5 or 33% Roundup Ultra may also control this weed.
[d]Use either the high rate or a split application for this degree of control.
[e]Use only with STS-designated soybean varieties.
[f]Label specifies high rate and favorable environmental conditions required for suppression.
[g]Label specifies the use of COC and a maximum of 6-leaf stage for suppression.
[h]Flexstar may provide greater suppression than Reflex.
[i]Liberty is to be used only on Liberty Link–designated soybean varieties.

Roundup Ready soybean varieties allow Roundup Ultra to be applied for suppression or control of certain perennial broadleaf and grass weed species. Roundup Ultra at 2 quarts in 5 to 20 gallons of spray solution per acre controls or suppresses Canada thistle, common milkweed, hemp dogbane, horsenettle, swamp smartweed (Table 15.28), quackgrass, johnsongrass, or wirestem muhly (Table 15.19). Sequential applications of 1 quart followed by 1 quart may be more effective for some species. *Do not exceed a total of 3 quarts per acre*, the maximum total in-crop rate including preharvest treatment.

Assure II or **Matador, Fusion, Fusilade DX, Poast Plus** or **Prestige,** and **Select** provide postemergence control of johnsongrass, quackgrass, and wirestem muhly in soybeans. See Table 15.19 for ratings and Table 15.20 for rates and sizes.

Contact Herbicides to Suppress Perennial Weeds

Several postemergence contact herbicides used in corn and soybeans suppress certain perennial weeds by burning off top growth. This treatment may reduce competition with the crop, but it does not prevent regrowth from plant roots because contact herbicides translocate very little. When selecting a contact herbicide to control annual weeds, however, you may want to select one that suppresses problem perennials.

Buctril, Moxy, Laddok S-12, and Liberty or Liberty ATZ are contact herbicides used in corn; see "Contact Broadleaf Herbicides (Corn)." See the label or Table 15.16 for adjuvants. **Buctril** or **Moxy** at 1.5 pints per acre suppresses 8-inch to bud-stage Canada thistle in corn. A tank mix with Stinger or Banvel controls

Canada thistle, plus Banvel helps suppress field bindweed (see the label).

Laddok S-12RUP at 2.33 pints per acre suppresses 1- to 4-inch yellow nutsedge and 8- to 10-inch Canada thistle or field bindweed. A tank mix with Stinger controls Canada thistle, whereas a tank mix with 2,4-D LVE may help control field bindweed and swamp smartweed (see the label). *Do not apply Laddok S-12 after corn is 12 inches tall.*

Liberty at 28 fluid ounces or **Liberty ATZ**RUP at 40 fluid ounces per acre suppresses most perennial weeds and provides control of several when followed by another application of Liberty at 28 fluid ounces.

Basagran, Blazer or Status, Cobra, Flexstar, Liberty, and Reflex are contact herbicides used in soybeans; see "Contact Herbicides for 'Postemergence Control' of Broadleaf Weeds (Soybeans)" and Table 15.28. See the label or Table 15.26 for needed adjuvants.

Basagran applied at 1.5 to 2 pints per acre plus a COC suppresses or controls 8-inch Canada thistle and 6-inch yellow nutsedge. A second application or cultivation 7 to 10 days later improves control. Basagran applied at 2 to 3 pints per acre suppresses up to 10-inch field or hedge bindweed. **Blazer** or **Status** at 1.5 pints per acre suppresses field or hedge bindweed, common milkweed, and trumpet creeper.

Cobra at 12.5 fluid ounces per acre suppresses up to 6-leaf Canada thistle, common milkweed, bigroot morningglory (wild sweet potato), swamp smartweed, and trumpet creeper. **Reflex** or **Flexstar** at 1.25 pints per acre suppresses field or hedge bindweed, honeyvine milkweed, trumpet creeper, and yellow nutsedge. **Liberty** at 28 fluid ounces per acre suppresses most perennial weeds and provides control of several when followed by another application of Liberty at 28 fluid ounces.

Contributions of other weed scientists and staff of the University of Illinois and at other institutions, as well as the input of industry weed scientists, are gratefully acknowledged.

Authors

M. McGlamery, A. Hager, and **D. Pike**
Department of Crop Sciences

Chapter 16. 1999 Weed Control for Small Grains, Pastures, and Forages

Good weed control is necessary for maximum production of high-quality small grains, pastures, and forages in Illinois. When properly established, these crops usually can compete effectively with weeds, so the need for herbicide applications is minimized. However, weeds can sometimes become significant problems and warrant control. For example, wild garlic is considered the worst weed problem in wheat in southern Illinois. Because its life cycle is similar to that of winter wheat, wild garlic can establish itself with the wheat, grow to maturity, and produce large quantities of aerial bulblets by wheat-harvest time. Economics often makes it necessary to control wild garlic in winter wheat to minimize dockage.

In pastures, woody and herbaceous perennials can become troublesome. Annual grasses and broadleaf weeds such as chickweed and henbit may cause problems in hay crops. By proper management, many of these weed problems can be controlled effectively.

Several herbicide labels carry the following groundwater warnings under either the environmental hazard or the groundwater advisory section: "X is a chemical that can travel (seep or leach) through soil and enter groundwater that may be used as drinking water. X has been found in groundwater as a result of its use as a herbicide. Users of this product are advised not to apply X where the soils are very permeable (that is, well-drained soils such as loamy sands) and the water table is close to the surface." Table 16.01 lists herbicides that carry this warning. A few labels also warn against contamination of surface water.

Small Grains

Good weed control is critical for maximum production of high-quality small grains. Often, problems with weeds may be dealt with before the crop is established. For example, some broadleaf weeds can be controlled effectively in the late fall with **2,4-D** or **Banvel** (dicamba), or with **Roundup Ultra** (glyphosate) after corn or soybean harvest, if seeding is not too late.

Tillage helps control weeds. Although generally limited to preplant or postharvest operations, tillage can destroy many annual weeds and help suppress certain perennials. Good cultural practices such as proper seeding rate, optimal soil fertility, and timely planting help to ensure the establishment of an excellent stand and a crop that is better able to compete with weeds.

Winter annual grasses such as downy brome and cheat are very competitive in winter wheat. Illinois wheat producers are often limited to preplant tillage operations for control of these species, as few herbicides have label clearances for annual grass control in winter wheat. If there is a severe infestation of downy brome or cheat, planting an alternative crop or spring crop may be best for that field.

A decision to use postemergence herbicides for broadleaf weed control in small grains should be based on several considerations:

1. *Nature of the weed problem.* Identify the species present and consider the severity of the infestation. Also note the size of the weeds. Weeds are usually best controlled while small.
2. *Stage of the crop.* Most herbicides are applied after full-tiller until the boot stage. Do not apply herbicides from the boot stage to the hard-dough stage of small grains (see Figure 16.01 for a description of growth stages of small grains).

The information in this chapter is provided for educational purposes only. Product trade names have been used for clarity, but reference to trade names does not imply endorsement by the University of Illinois; discrimination is not intended against any product. The reader is urged to exercise caution in making purchases or evaluating product information.

Label registrations can change at any time. Thus the recommendations in this chapter may become invalid. The user must read carefully the entire, most recent label and follow all directions and restrictions. Purchase only enough pesticide for the current growing season.

Table 16.01. Herbicides, Formulations, and Special Statements

Trade name	Common name	Formulation	Restricted use	Groundwater advisory	Key word
2,4-D amine	2,4-D	3.8 lb a.e./gal[a]	—	—	**Danger**[b]
2,4-D ester	2,4-D	3.8 lb a.e./gal[a]	—	—	Caution
Ally 60DF	metsulfuron	60%	—	—	Caution
Balan 60DF	benefin	60%	—	—	Warning
Banvel	dicamba	4 lb a.e./gal[a]	—	—	Warning
Buctril	bromoxynil	2 lb/gal	—	—	Warning
Butyrac 200	2,4-DB	2 lb a.e./gal[a]	—	Yes	**Danger**[b]
Crossbow	2,4-D + triclopyr	2 + 1 lb a.e./gal[a]	—	Yes	Caution
Eptam 7E, 10G	EPTC	7 lb/gal, 10%	—	—	Caution
Fusilade DX	fluazifop	2 lb a.e./gal[a]	—	—	Caution
Gramoxone Extra	paraquat	2.5 lb/gal	Yes	—	**Danger**[b]
Harmony Extra 75DF	thifensulfuron + tribenuron	75%	—	—	Caution
Kerb 50W	pronamide	50%	Yes	—	Caution
Lexone 75DF	metribuzin	75%	—	Yes	Caution
MCPA	MCPA	several	—	—	Warning
Peak 57WG	prosulfuron	57%	—	—	Caution
Poast Plus	sethoxydim	1 lb/gal	—	—	Caution
Prowl	pendimethalin	3.3 lb/gal	—	—	Caution
Pursuit 2AS, 70DG	imazethapyr	2 lb/gal, 70%	—	—	Caution, Warning
Roundup Ultra	glyphosate	3 lb a.e./gal[a]	—	—	Caution
Sencor 75DF	metribuzin	75%	—	Yes	Caution
Sinbar 80W	terbacil	80%	—	—	Caution
Spike 20P	tebuthiuron	20%	—	Yes	Caution
Stinger	clopyralid	3 lb a.e./gal[a]	—	Yes	Caution
Select	clethodim	2 lb/gal	—	—	Warning
Treflan	trifluralin	4 lb/gal, 5 lb/gal, 10G	—	—	Warning
Velpar L	hexazinone	2 lb/gal	—	—	**Danger**[b]
Weedmaster	dicamba + 2,4-D	1 + 2.87 lb/gal	—	—	**Danger**[b]

[a]a.e. = acid equivalent for these herbicides. All others are active ingredient (a.i.) formulations.
[b]**Danger:** Check label for safety equipment and precautions.

3. *Herbicide activity.* Determine crop tolerance and weed susceptibility to herbicides by referring to Tables 16.02 and 16.03. The lower rates in Table 16.03 are for more easily controlled weeds and the higher rates for the more difficult-to-control species. Tank mixes may broaden the weed spectrum and thereby improve control; check the herbicide label for registered combinations.

4. *Presence of a legume underseeding.* Usually 2,4-D ester formulations and certain other herbicides listed in Table 16.03 should not be applied because they may damage the legume underseeding.

5. *Economic justification.* Consider the treatment cost in terms of potential benefits, such as the value of increased yield, improved quality of grain, and ease of harvesting the crop.

Table 16.03 outlines current suggestions for weed-control options in wheat and oats, the two small grains most commonly grown in Illinois. Please refer to Table 16.04 for grazing-restriction information concerning herbicides used in small grains. Always consult the herbicide label for specific information about the use of a given product.

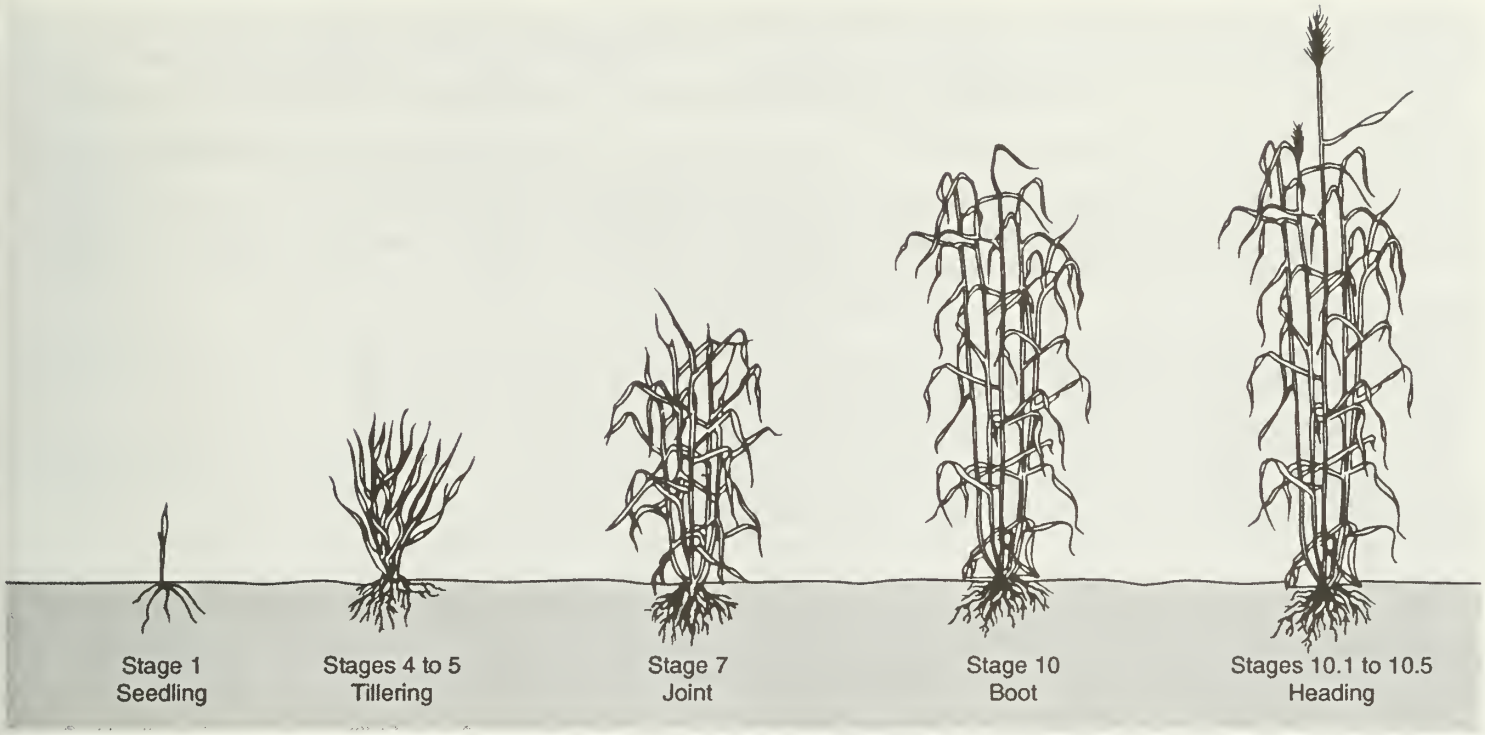


Figure 16.01. Growth stages of small grains.

Seedling

Stage 1. The coleoptile, a protective sheath that surrounds the shoot, emerges. The first leaf emerges through the coleoptile, and other leaves follow in succession from within the sheath of the previously emerging leaf.

Tillering

Stages 2 to 3. Tillers (shoots) emerge on opposite sides of the plant from buds in the axils of the first and second leaves. The next tillers may arise from the first shoot at a point above the first and second tillers or from the tillers themselves. This process is repeated until a plant has several shoots.

Stages 4 to 5. The leaf sheaths lengthen, giving the appearance of a stem. The true stems in both the main shoot and the tillers are short and concealed within the leaf sheaths.

Jointing

Stage 6. The stems and leaf sheaths begin to elongate rapidly, and the first node (joint) of the stem is visible at the base of the shoot.

Stage 7. The second node (joint) of the stem is visible. The next-to-last leaf is emerging from within the sheath of the previous leaf but is barely visible.

Stage 8. The last leaf, the "flag leaf," is visible but still rolled.

Stage 9. Preboot stage. The ligule of the flag leaf is visible. The head begins to enlarge within the sheath.

Stage 10. Boot stage. The sheath of the flag leaf is completely emerged and distended due to the enlarging but not yet visible head.

Heading

Stages 10.1 to 10.5. Heads of the main stem usually emerge first, followed in turn by heads of the tillers in order of their development. Heading continues until all heads are out of their sheaths. The uppermost internode continues to lengthen until the head is raised several inches above the uppermost leaf sheath.

Flowering

Stages 10.5.1 to 10.5.3. Flowering progresses in order of head emergence. Unpollinated flowers result in no kernels.

Stage 10.5.4. Premilk stage. Flowering is complete. The inner fluid is abundant and clear in the developing kernels of the flowers pollinated first.

Ripening

Stage 11.1. Milk stage. Kernel fluid is milky white from the accumulating starch.

Stage 11.2. Dough stage. Kernel contents are soft and dry (doughy) as starch accumulation continues. The plant leaves and stems are yellow.

Stage 11.3. The kernel is hard, difficult to divide with the thumbnail.

Stage 11.4. The kernel is ripe for cutting and fragments when crushed. The plant is dry and brittle.

Table 16.02. Effectiveness of Herbicides on Weeds in Small Grains

This table compares the relative effectiveness of herbicides on individual weeds. Ratings are based on labeled application rate and weed size or growth stage. Performance may vary due to weather and soil conditions or other variables.

	Susceptibility to herbicide						
Weed	2,4-D	Banvel	Buctril	Harmony Extra	MCPA	Peak	Stinger
Winter annual							
Buckwheat, wild	5	9	9	8	6	8	8
Chickweed, common	5	7	6	9	5	8	0
Henbit	5	8	8	9	5	7	0
Horseweed (marestail)	8	8	7	8	7	7	8
Lettuce, prickly	9	8	7	8	8	8	8
Mustard spp., annual	9	7	8	9	8	9	0
Pennycress, field	9	7	8	9	8	9	0
Shepherd's purse	9	8	9	9	8	8	0
Summer annual							
Lambsquarters, common	9	9	9	9	9	7	0
Pigweed spp.	9	9	7	9	8	7	0
Ragweed, common	9	9	9	8	9	8	8
Ragweed, giant	9	9	8	5	9	7	9
Smartweed, Pennsylvania	7	9	8	9	7	7	7
Perennial							
Dandelion	9	8	0	6	8	5	9
Garlic, wild							
Aerial bulblets	6*	5	0	9	5	9	0
Underground bulbs	0	0	0	5	0	5	0
Thistle, Canada	7	8	6	7	6	7	9

9 = 90 to 100%, 8 = 80 to 89%, 7 = 70 to 79%, 6 = 60 to 69%, 5 = 50 to 59%, 0 = less than 50% control or not labeled.
*2,4-D ester at maximum use rate.

For annual broadleaf weeds, postemergence herbicides such as **2,4-D, Banvel, Buctril** (bromoxynil), and **MCPA** can provide good control of susceptible species (Table 16.02). Herbicides must be applied during certain growth stages of the crop to avoid crop injury and for optimal weed control. Refer to Figure 16.01 for a description of the growth stages of small grains.

Some perennial broadleaf weeds may not be controlled satisfactorily with the low herbicide rates used in small grains, and higher rates are not advisable because they can cause serious injury to crops. To control perennial weeds, translocated herbicides such as **2,4-D, Banvel,** or **Roundup Ultra,** in combination with tillage after small grain harvest or after soybean harvest but before establishing small grains, may be the best approach.

Stinger (clopyralid) may be used to control broadleaf weeds in wheat, oats, and barley. Stinger controls Canada thistle, as well as a number of annual broadleaf weeds (Table 16.02).

Wild garlic continues to be a serious weed problem in winter wheat. **Harmony Extra** (thifensulfuron + tribenuron), applied in the spring at 0.3 to 0.6 ounce of 75DF per acre, effectively controls wild garlic aerial bulblets and some underground bulbs as well. Harmony Extra also helps control chickweed, henbit, common lambsquarters, smartweed, and several species of mustard. See Tables 16.02 and 16.03 for more information on controlling weeds in small grains.

Roundup Ultra may be used as a preharvest treatment in wheat for control of annual and certain perennial weed species. Applications should be made only after the hard-dough stage of the grain (30 percent or less grain moisture) and at least 7 days before harvest. Roundup Ultra may be applied at a maximum rate of 1 quart per acre using ground or aerial application

Table 16.03. Weed Control in Small Grains

Herbicide	Broadcast rate/acre	Remarks (see Table 16.04 for grazing restrictions)
Oats and wheat with legume underseeding		
2,4-D amine (3.8 lb a.e.)	½ to 1½ pt	Winter wheat more tolerant than oats. Apply in spring after full tiller but before joint stage. Do not treat in the fall. Use lower rate if underseeded with legume. Some legume damage may occur. May be used as preharvest treatment at 1 to 2 pt per acre during hard-dough stage.
Buctril 2E	1 to 1.5 pt	Apply Buctril alone to fall-seeded small grains in the fall or spring before the boot stage. Weeds are best controlled before the 3- to 4-leaf stage. Buctril 2E may be applied at 1 to 1½ pt per acre to small grains underseeded with alfalfa.
MCPA amine	¼ to 1.5 pt	Less likely than 2,4-D to damage oats and legume underseeding. Apply from 4-leaf stage to joint stage. Rate varies with crop and weed size and presence of legume underseeding.
Oats and wheat without legume underseeding		
Banvel, 4 lb a.e.	4 fl oz	*Do not use with legume underseeding.* In fall-seeded wheat, apply before jointing stage. In spring-seeded oats, apply before oats exceed 5-leaf stage.
Harmony Extra 75DF	0.3 to 0.6 oz	*Do not use with legume underseeding.* Make applications to wheat after the crop is in the 2-leaf stage, but before the flag leaf is visible. For spring oats, make applications after the crop is in the 3-leaf stage but before jointing. The use rate for spring oats is 0.3 to 0.4 oz per acre. Wild garlic should be less than 12 in. tall, with 2 to 4 in. of new growth. Annual broadleaf weeds should be past the cotyledon stage, actively growing, and less than 4 in. tall or across. Nonionic surfactant at 0.25% volume per volume (v/v) should be included in the spray mixture. When liquid fertilizer is used as the carrier, use 1/16–¼% v/v surfactant. Temporary stunting and yellowing may occur when Harmony Extra is applied using liquid fertilizer solution as the carrier. These symptoms are intensified with the addition of surfactant. Without surfactant addition, wild garlic control may be erratic. Do not plant any crop other than wheat or oats within 60 days after application.
Peak 57WG	0.38 to 0.5 oz	*Do not use with legume underseeding.* Apply Peak to actively growing small grain crops from the 3-leaf stage to before the second node is detectable in stem elongation. Applications made to small grains before the 3-leaf stage increase likelihood of crop injury. Do not make a foliar or soil application of an organophosphate insecticide within 15 days before or 10 days after applying Peak. Always include a COC (1 to 4 pints per acre) or NIS (1 to 2 quarts per 100 gallons) in the spray mix, and apply in at least 10 gallons of water per acre. Do not harvest grain until 60 days after application, and apply no more than 1 ounce of Peak per growing season. *Do not plant soybeans until 10 months after application.*
Stinger, 3 lb a.e.	¼ to ⅓ pt	*Do not use with legume underseeding.* Apply to small grains from the 3-leaf stage up to the early boot stage. For control of Canada thistle, ⅓ pt per acre should be used. For control of additional weeds, 2,4-D, Banvel, Buctril, Harmony Extra, Sencor, or MCPA may be tank-mixed with Stinger.
Wheat only 2,4-D ester, 3.8 lb a.e.	½ to 1 pt	*Do not use with legume underseeding.* Apply in the spring after full-tiller but before joint stage. For preharvest treatment, apply 1 to 2 pt per acre during hard-dough stage. For control of wild garlic or wild onion, apply 1 to 2 pt in the spring when wheat is 4 to 8 in. tall, after tillering but before jointing; these rates may injure the crop and only suppress wild garlic.
Roundup Ultra 3 lb a.e./gal	1 to 2 pt	*Do not use with legume underseeding.* Apply as a preharvest treatment only after the hard-dough stage of grain (30% or less moisture) and at least 7 days before harvest. It is not recommended that wheat being grown for seed be treated with Roundup Ultra because a reduction in germination or vigor may occur.

Table 16.04. Grazing Restrictions for Small Grain Herbicides

Herbicide name				Days after treatment before use			
				Graze green			
Trade	Common	Crops	Applied	Beef	Dairy	Feed straw	Withdraw for meat
Banvel	dicamba	wheat, oats, barley	Prejoint	0	7	37	30
Buctril	bromoxynil	wheat, oats, rye, barley	Preboot	30	30	30	30
Harmony Extra	2:1 mixture of thifensulfuron + tribenuron	triticale wheat, barley, spring oats	Before flagleaf Prejoint	No	No	Yes	0
Many	2,4-D	wheat, oats, rye, barley	Prejoint	14	14	0	14
Many	2,4-D, late	wheat, oats, rye, barley	Before harvest	No	No	No	. . .*
Many	MCPA	wheat, oats, rye, barley	Prejoint	7	7	0	7
Peak	prosulfuron	wheat, oats, rye, barley	Prior to second node	30	30	30	. . .*
Roundup Ultra	glyphosate	wheat	Before harvest	14	14	14	. . .*
Stinger	clopyralid	wheat, oats, barley	Preboot	7	7	No	7

*No withdrawal information available.

equipment. It is not recommended that wheat being grown for seed be treated with Roundup because a reduction in germination or vigor may occur.

Grass Pastures

Unless properly managed, broadleaf weeds can become a serious problem in grass pastures. They can compete directly with forage grasses and reduce the nutritional value and longevity of the pasture. Certain species, such as white snakeroot and poison hemlock, are also poisonous to livestock and may require special consideration.

Perennial weeds are of great concern in pasture management. They can exist for many years, reproducing from both seed and underground parent rootstocks. Occasional mowing or grazing helps control certain annual weeds, but perennials can grow back from underground root reserves unless long-term control strategies are implemented.

Certain biennials can also flourish in grass pastures. The first year, they exist as a prostrate rosette, so that even close mowing does little to control their growth. The second year, biennials produce a seed stalk and a deep taproot. If these weeds are grazed or mowed at this stage, root reserves can enable the plant to grow again, thereby increasing its chance of surviving to maturity.

In general, the use of good cultural practices such as maintaining optimal soil fertility, rotational grazing, and periodic mowing can help keep grass pastures in good condition and more competitive with weeds. Where broadleaf weeds become troublesome, however, **2,4-D, Banvel, Stinger,** or **Weedmaster** (dicamba + 2,4-D) may be used. **Roundup Ultra** also may be used as a spot treatment, and **Crossbow** (2,4-D + triclopyr) and **Ally** (metsulfuron methyl) are labeled for control of broadleaf and woody plant species in grass pastures. **Spike 20P** (tebuthiuron) also may be used in grass pastures for control of brush and woody plants (see Tables 16.05 and 16.06 for additional information).

Proper identification of target weed species is important. As shown in Table 16.05, weeds vary in their susceptibility to herbicides. Timing of herbicide application also may affect the degree of weed control. Annuals and biennials are most easily controlled while young and relatively small. A fall or early spring herbicide application works best if biennials or winter annuals are the main weed problem. Summer annuals are most easily controlled in the spring or early summer. Apply translocated herbicides to control established perennials when the weeds are in the bud-to-bloom stage. Perennials are most susceptible at this reproductive stage because translocated herbicides can move downward with food reserves to the roots, thus killing the entire plant.

For control of woody brush, apply **2,4-D, Banvel,** or **Crossbow** when the plants are fully leafed and actively growing. Where regrowth occurs, a second treatment may be needed in the fall. During the dormant season, oil-soluble formulations of **2,4-D, Banvel,** or **Crossbow** may be applied in fuel oil to the trunk. **Spike** controls many woody perennials and

Table 16.05. Effectiveness of Herbicides on Weeds in Grass Pastures

This table compares the relative effectiveness of herbicides on individual weeds. Ratings are based on labeled application rate and weed size or growth stage. Performance may vary due to weather and soil conditions or other variables.

	Susceptibility to herbicide					
Weed	2,4-D	Ally	Banvel	Crossbow	Roundup[a]	Stinger
Winter annual						
Horseweed (marestail)	9	9	9	9	9	8
Pennycress, field	9	8	8	9	9	0
Summer annual						
Ragweed, common	9	7	9	9	9	9
Ragweed, giant	9	8	9	9	9	9
Biennial						
Burdock, common	9	0	9	9	8	8
Hemlock, poison	8	0	9	8	8	0
Thistle, bull	9	8	9	9	9	9
Thistle, musk	8	9	9	9	9	8
Perennial[b]						
Daisy, oxeye	8	0	9	9	8	8
Dandelion	9	0	8	9	7	8
Dock, curly	7	9	9	9	8	7
Goldenrod spp.	8	5	9	8	9	5
Hemlock, spotted water	8	0	9	9	8	5
Ironweed	8	5	8	8	9	5
Milkweed, common	6	0	7	7	7	0
Nettle, stinging	8	0	8	8	8	7
Plantain spp.	9	9	8	9	9	0
Rose, multiflora[c]	7	8	8	9	8	0
Snakeroot, white	8	0	9	9	8	0
Sorrel, red	5	9	9	9	8	7
Sowthistle, perennial	8	0	9	9	8	7
Thistle, Canada	7	8	9	9	8	9

9 = 90 to 100%, 8 = 80 to 89%, 7 = 70 to 79%, 6 = 60 to 69%, 5 = 50 to 59%, 0 = less than 50% control or not labeled.
[a]Spot treatment only.
[b]Perennial weeds may require more than one application.
[c]Spike also is an effective herbicide for multiflora rose control (weed susceptibility = 9).

should be applied to the soil in the spring. Spike requires rainfall to move it into the root zone of target species. **Ally** as a spot treatment controls multiflora rose, Canada thistle, and blackberry (*Rubus* spp.) and controls several annual broadleaf weeds when applied as a broadcast treatment at the lower rate range.

The weed control options in grass pastures are shown in Table 16.06. Refer to Table 16.07 for information concerning grazing restrictions for herbicides used in grass pastures. Be cautious with any pesticide, and always consult the herbicide label for specific information about the use of a given product.

Forage Legumes

Weed control is important in managing forage legumes. Weeds can reduce the vigor of legume stands, reducing yield and forage quality. Good management begins with weed control that prevents weeds from becoming serious problems.

Establishment

To minimize problems, prepare the seedbed properly so that it is firm and weed free. Select an appropriate legume variety. If you use high-quality seed and follow

Table 16.06. Broadleaf Weed Control in Grass Pastures

Herbicide	Rate/acre	Remarks (see Table 16.07 for grazing restrictions)
2,4-D, 3.8 lb a.e. (amine or low-volatile ester)	2 to 4 pt	Broadleaf weeds should be actively growing. Higher rates may be needed for less-susceptible weeds and some perennials. Spray bull or musk thistles in the rosette stage (spring or fall) while they are actively growing. Spray perennials such as Canada thistle in the bud stage or the fall regrowth stage. Spray susceptible woody species in the spring when leaves are fully expanded. Do not apply to newly seeded areas or to grass when it is in boot-to-milk stage. Be cautious of spray drift.
Ally 60DF	0.1 to 0.3 oz	Apply in the spring or early summer before annual broadleaf weeds are 4 in. tall. As a spot application for control of multiflora rose, blackberry, or Canada thistle, apply Ally at 1 oz per 100 gal of water and spray foliage to runoff. Include a nonionic surfactant of at least 80% active ingredient at 1 pt to 1 qt per 100 gal spray solution (⅛% to ¼% v/v). Bluegrass, bromegrass, orchardgrass, timothy, and native grasses such as bluestem and grama have demonstrated good tolerance. Bluegrass, bromegrass, orchardgrass, and timothy should be established for at least 6 months and fescue for 24 months at the time of application, or injury may result. Application to fescue may result in stunting and seedhead suppression. Do not apply to ryegrass or pastures containing desirable alfalfa or clovers. Ally is persistent in soil, and crop rotation guidelines on the label must be followed.
Banvel, 4 lb a.e.	Annuals: 0.5 to 1½ pt Biennials: ½ to 3 pt Perennials: 2 to 4 pt	Use lower rates for susceptible annuals when they are small and actively growing and for susceptible biennials in the early rosette stage. Use higher rates for larger weeds, for less susceptible weeds, for established perennials in dense stands, and for certain woody brush species. Be cautious of spray drift.
Crossbow	Annuals: 1 to 2 qt Biennials and herbaceous perennials: 2 to 4 qt Woody perennials: 6 qt	Apply to foliage during warm weather when brush and broadleaf weeds are actively growing. When applying as a spot spray, thoroughly wet all foliage. See herbicide label for more specific rate recommendations. Be cautious of spray drift. Best control of multiflora rose occurs when application is made during early to mid-flowering stage.
Roundup Ultra	1 to 2% solution (spot treatment)	Controls a variety of herbaceous and woody brush species, such as multiflora rose, brambles, poison ivy, and quackgrass. Spray foliage of target vegetation completely and uniformly, but not to point of runoff. Avoid contact with desirable nontarget vegetation. Consult label for recommended timing of application for maximum effectiveness on target species. No more than 1⁄10 of any acre should be treated at one time. Further applications may be made in the same area at 30-day intervals. Use only where livestock movement can be controlled to prevent grazing for 14 days. Treated areas may be reseeded after 14 days.

Table 16.06. Broadleaf Weed Control in Grass Pastures (cont.)

Herbicide	Rate/acre	Remarks (see Table 16.07 for grazing restrictions)
Spike 20P	10 to 20 lb	For control of brush and woody plants in rangeland and grass pastures. Requires sufficient rainfall to move herbicide into root zone. May kill or injure desirable legumes and grasses where contact is made. Injury is minimized by applying when grasses are dormant. Do not apply on or near field crops or other desirable vegetation. Do not apply where soil movement is likely. Refer to product label for additional restrictions.
Stinger, 3 lb a.e.	⅔ to 1⅓ pt	Apply when weeds are young and actively growing. Grasses are tolerant, but new grass seedlings may be injured. For Canada thistle, apply to thistle at least 4 in. tall but before thistle reaches bud stage. Do not spray pastures containing desirable forbs, such as alfalfa or clover, unless injury can be tolerated. Do not use hay or straw from treated areas for composting or mulching on susceptible broadleaf crops. Refer to product label for additional precautions.

Table 16.07. Restrictions on Herbicides Used in Permanent Grass Pastures

Herbicide name		Days after treatment before use				
		Grazing		Grass hay		Slaughter withdrawal
Trade	Common	Beef	Dairy	Beef	Dairy	
Ally	metsulfuron	0	0	0	0	0
Banvel < 4 pt	dicamba	0	7 to 40[a]	0	37 to 70[a]	30
Crossbow	triclopyr + 2,4-D	0	14	7	365	3
Many	2,4-D	0	7 to 14[b]	30	30	3 to 7[b]
Stinger[c]	clopyralid	0	0	0	0	0
Roundup	glyphosate					
Spot-treat		14	14	14	14	. . .[d]
Renovation		56	56	56	56	. . .[d]
Spike 20P	tebuthiuron	(spot treatment)				
< 20 lb/acre		0	0	365	365	. . .[d]
> 20 lb/acre		*Do not use for livestock for 1 year.*				
Weedmaster	dicamba + 2,4-D	0	7	37	37	30

[a]Varies with rate used per acre—see label.
[b]Labels vary (withdrawal unnecessary if more than 14 days after treatment).
[c]Do not transfer livestock onto a broadleaf crop area within 7 days of grazing treated area.
[d]No information available.

the recommendations for liming and fertility, the legume crop may compete well with many weeds and reduce the need for herbicides.

In fields where companion crops such as oats are used to reduce weed competition, seed the small grain at half the rate for grain production to ensure that the legumes become established with minimum stress. If the legume is seeded without a companion crop (direct-seeded), the use of an appropriate herbicide is suggested.

Preplant-Incorporated Herbicides

Balan (benefin), Eptam (EPTC), and **Treflan** (trifluralin) are registered for preplant incorporation for legumes that are not seeded with grass or small-grain companion crops. These herbicides control most annual grasses and some broadleaf weeds. In fall plantings, the weeds controlled include winter annuals such as downy brome and cheat. In spring

Table 16.08. Effectiveness of Herbicides on Weeds in Legume and Legume-Grass Forages

This table compares the relative effectiveness of herbicides on individual weeds. Ratings are based on labeled application rate and weed size or growth stage. Performance may vary due to weather and soil conditions or other variables.

Weed	Balan	Buctril	Butyrac	Eptam	Gramoxone Extra	Kerb	Poast Plus	Pursuit	Round-up[a,b]	Select	Sencor/ Lexone[a]	Sinbar	Velpar
Winter annual													
Brome, downy	9	0	0	9	8	9	8	6	9	9	8	9	9
Chickweed, common	8	7	6	7	9	8	0	9	9	0	9	9	9
Henbit	5	8	6	9	9	8	0	7	8	0	9	9	8
Mustard, wild	0	8	8	6	8	5	0	9	9	0	9	9	9
Pennycress, field	0	9	8	6	7	5	0	9	9	0	9	9	9
Shepherd's purse	0	9	8	7	7	5	0	8	9	0	9	9	9
Yellow rocket	0	7	7	6	8	0	0	7	9	0	9	9	9
Summer annual													
Barnyardgrass	9	0	0	9	8	8	9	7	9	9	8	7	8
Crabgrass spp.	9	0	0	9	6	8	9	7	9	9	7	7	7
Foxtail spp.	9	0	0	9	9	8	9	8	9	9	6	7	7
Lambsquarters, common	9	9	8	9	8	7	0	6	9	0	9	9	9
Nightshade spp.[c]	0	9	8	8	9	6	0	9	9	0	5	8	7
Panicum, fall	9	0	0	9	9	6	9	7	9	9	6	6	6
Pigweed spp.	9	8	8	9	8	6	0	9	9	0	9	8	9
Ragweed, common	0	9	9	5	9	5	0	7	9	0	8	8	8
Smartweed, Pennsylvania	0	9	6	5	8	5	0	9	9	0	8	8	8
Perennial													
Canada thistle	0	5	5	0	0	0	0	6	9	0	0	0	0
Dandelion	0	0	7	0	0	0	0	7	8	0	7	6	8
Dock, curly	0	0	5	0	0	0	0	6	9	0	6	6	7
Nutsedge, yellow	0	0	0	8	0	0	0	6	7	0	0	0	0
Orchardgrass	5	0	0	6	5	7	6	0	8	7	5	5	7
Quackgrass	6	0	0	8	5	8	7	5	9	8	5	6	6

9 = 90 to 100%, 8 = 80 to 89%, 7 = 70 to 79%, 6 = 60 to 69%, 5 = 50 to 59%, 0 = less than 50% control or not labeled.
[a]Lexone, Roundup, and Sencor are labeled for use in mixed legume-grass forages. No other herbicides are cleared for this use.
[b]Spot treatment only.
[c]Control of different species may vary.

plantings of legumes, the summer annual weeds controlled include foxtails, pigweeds, lambsquarters, crabgrass, and fall panicum. Eptam can help suppress johnsongrass, quackgrass, yellow nutsedge, and shattercane, in addition to controlling many annual grasses and some broadleaf weeds. These herbicides do not effectively controls mustards, smartweed, or established perennials.

Balan, Eptam, and Treflan must be thoroughly incorporated soon after application to avoid herbicide loss. They should be applied shortly before the legume is seeded to remain effective as long as possible into the growing season.

Weeds that emerge during crop establishment should be evaluated for their potential as problems. If they do not reduce the nutritional value of the forage or if they can be controlled by mowing, they should not be the primary focus of a postemergence herbicide application. For example, winter annual weeds do not compete vigorously with the crop after the first cutting in the spring. Unless they are unusually dense or production of weed seed becomes a concern, these

Table 16.09. Weed Control in Legume Forages

Herbicide	Legume	Time of application	Broadcast rate/acre	Remarks (see Table 16.10 for haying restrictions)
Seedling year				
Balan 60DF	Alfalfa, birdsfoot trefoil, red clover, ladino clover, alsike clover	Preplant incorporated	2 to 2.5 lb	Apply shortly before seeding. Do not use with any companion crop of small grains.
Buctril 2E	Alfalfa only	Postemergence	1 to 1.5 pt	Apply in the fall or spring to seedling alfalfa with at least 4 trifoliate leaves. Apply to weeds at or before the 4-leaf stage or 2 in. in height (whichever is first). May be tank-mixed with 2,4-DB for improved control of pigweed; however, crop burn may occur from this mixture, especially under warm, humid conditions. Eptam, previously used, may enhance Buctril burn to alfalfa. Do not apply when temperatures are likely to exceed 70°F during or for 3 days following application or when the crop is stressed. Do not add a surfactant or crop oil.
Butyrac 200 or Butoxone 200	Alfalfa, birdsfoot trefoil, ladino clover, red clover, alsike clover, white clover	Postemergence	1 to 3 qt (amine)	Use when weeds are less than 3 in. tall or less than 3 in. across if rosettes. Use higher rates for seedling smartweed or curly dock. May be tank-mixed with Poast Plus. *Do not use on sweet clover.*
Eptam 7E, 20G	Alfalfa, birdsfoot trefoil, lespedeza, clovers	Preplant incorporated	3½ to 4½ pt (7E) 15 lb (20G)	Apply shortly before seeding. Do not use with any companion crop of small grains.
Gramoxone Extra	Alfalfa only	Between cuttings	12.8 fl oz	Apply within 5 days after cutting and before alfalfa regrowth is 2 in. Add surfactant according to label instructions. Do not apply more than twice during seedling year. *Gramoxone Extra is a restricted-use pesticide.*
Kerb 50W	Alfalfa, birdsfoot trefoil, crown vetch, clovers	Postemergence	1 to 3 lb	In fall-seeded legumes, apply after legumes have reached trifoliate stage. In spring-seeded legumes, apply the next fall. *Kerb 50W is a restricted-use pesticide.*
Poast Plus	Alfalfa only	Postemergence	1⅛ to 2¼ pt	Best grass control is achieved when applications are made prior to mowing. If tank-mixed with 2,4-DB, follow 2,4-DB harvest and grazing restrictions and add no additives with this tank mix. Do not apply more than a total of 9.75 pt of Poast Plus per acre in 1 season.
Pursuit 2AS or 70DG	Alfalfa	Postemergence	3 to 6 fl oz (2AS) 1.08 to 2.16 oz (70DG)	Apply when seedling alfalfa is in the second-trifoliate stage or larger and when the majority of weeds are 1 to 3 in. tall. For low-growing weeds, apply before the rosette exceeds 3 in. in diameter. Always include a nonionic surfactant

Table 16.09. Weed Control in Legume Forages (cont.)

Herbicide	Legume	Time of application	Broadcast rate/acre	Remarks (see Table 16.10 for haying restrictions)
Seedling year (cont.)				
Pursuit 2AS or 70DG (cont.)	Alfalfa	Postemergence	3 to 6 fl oz (2AS) 1.08 to 2.16 oz (70DG)	or crop oil concentrate and a liquid nitrogen fertilizer solution, and apply in 10 or more gallons of water per acre. When applied to seedling alfalfa, Pursuit may cause a temporary reduction in growth. Do not apply more than 6 fl oz or 2.16 oz per acre per year.
Select 2EC	Alfalfa	Postemergence	6 to 8 fl oz	May be applied to seedling or established alfalfa grown for seed, hay, silage, green chop, or direct grazing. If tank-mixed with 2,4-DB, follow 2,4-DB grazing and harvest restrictions. Do not plant rotational crops until 30 days after Select application.
Treflan HFP, TR-10	Alfalfa only	Preplant incorporated	1 to 1.5 pt (HFP) 5 to 7.5 lb (TR-10)	May be applied as a preplant incorporated treatment for preemergence control of certain grass and small-seeded broadleaf species. Some crop stand reduction and stunting may occur.
Established stands				
Butyrac 200 or Butoxone 200	Alfalfa only	Growing	1 to 3 qt (amine)	Spray when weeds are less than 3 in. tall or less than 3 in. wide if rosettes. Fall treatment of fall-emerged weeds may be better than spring treatment. May be tank-mixed with Poast Plus.
Gramoxone Extra	Alfalfa only	Between cuttings	12.8 fl oz	Between cuttings, treatments should be applied immediately after hay removal, within 5 days after cutting and with less than 2 in. of growth. Weeds germinating after treatment are not controlled. *Gramoxone Extra is a restricted-use pesticide.*
Gramoxone Extra	Alfalfa, Clover	Dormant	13 to 24 fl oz	For dormant season, apply after last fall cutting or before spring growth is 2 in. tall. Weeds should be succulent and growing at the time of application. Do not apply if fall regrowth is more than 6 in. *Gramoxone Extra is a restricted-use pesticide.*
Kerb 50W	Alfalfa, birdsfoot trefoil, crown vetch, clovers	Growing or dormant	1 to 3 lb	Apply in the fall after last cutting, when weather and soil temperatures are cool. *Kerb 50W is a restricted-use pesticide.*
Poast Plus 1E	Alfalfa	Postemergence	1⅛ to 2¼ pt	Best grass control is achieved when applications are made prior to mowing. If tank-mixed with 2,4-DB, follow 2,4-DB grazing and harvest restrictions. Do not apply more than a total of 9.75 pt of Poast Plus per acre in 1 season.
Pursuit 2AS or 70DG	Alfalfa only		3 to 6 fl oz (2 AS); 1.08 to 2.16 oz (70DG)	Apply in the fall or spring to dormant or semi-dormant alfalfa (less than 3 in. of regrowth), or between cuttings. Do not apply Pursuit to alfalfa during the last year of the stand. Always include a nonionic surfactant or crop oil concentrate and a liquid nitrogen fertilizer solution, and apply in 10 or more gallons of water per acre.

Table 16.09. Weed Control in Legume Forages (cont.)

Herbicide	Legume	Time of application	Broadcast rate/acre	Remarks (see Table 16.10 for haying restrictions)
Roundup	Alfalfa Alfalfa, clover, and alfalfa or clover-grass mixtures	Postemergence Growing	1 to 2% solution (spot treatment)	No more than 1/10 of any acre should be treated at one time. Further applications may be made in the same area at 30-day intervals. Avoid contact when desirable, nontarget vegetation because damage may occur. Refer to label for recommended timing of application for maximum effectiveness on target species.
	Alfalfa	Last cutting	1 to 2 pt	For use in declining alfalfa stands prior to crop rotation. Apply before last cutting in fall or spring for control of certain perennial grass and broadleaf weed species. Do not use for alfalfa grown for seed.
Select 2EC	Alfalfa	Postemergence	8 fl oz	For control of annual grasses in established alfalfa use a minimum of 8 fl oz/acre. If tank-mixed with 2,4-DB, follow 2,4-DB grazing and harvest restrictions.
Sencor or Lexone 750F	Alfalfa and alfalfa-grass mixtures	Dormant	1/2 to 1 1/3 lb	Apply once in the fall or spring before new growth starts. Rate is based upon soil type and organic-matter content. Higher rates may injure grass component. Do not use on sandy soils or soils with pH greater than 7.5.
Sencor 75DF	Alfalfa	Postdormant	1 to 1 1/3 lb	May be applied postdormant but prior to 3 in. of alfalfa top growth when impregnated on dry fertilizer.
Sinbar 80W	Alfalfa only	Dormant	1/2 to 1 1/2 lb	Apply once in the fall or spring before new growth starts. Use lower rates for coarser soils. Do not use on sandy soils with less than 1 percent organic matter. Do not plant any crop for 2 years after application.
Treflan TR-10 4EC	Alfalfa	Dormant or after a cutting during the growing season	 20 lb 4pt	A single rainfall or overhead sprinkler irrigation of 0.5 in. or more, flood irrigation, or furrow irrigation after application is required to activate the herbicide. If activation does not occur within 3 days after application, incorporate using equipment that provides thorough soil mixing with minimum damage to the established alfalfa. Treflan 4EC may be surface-applied or applied by chemigation. Do not apply Treflan TR-10 by chemigation.
Velpar L	Alfalfa only	Dormant	1 to 3 qt	Apply in the fall or spring before new growth exceeds 2 in. in height. May also be applied to stubble after hay crop removal but before regrowth exceeds 2 in. Do not plant any crop except corn within 2 years of treatment. Corn may be planted 12 months after treatment, provided deep tillage is used.

Table 16.10. Herbicides Used in Forage Legumes and Restrictions

Herbicide name		Applied on/at		Days before use	
Trade	Common	Forage[a]	When[a]	Graze	Hay
Seedling legumes					
Balan	benefin	AL, CL, BT	PPI	0	0
Eptam	EPTC	AL, CL, BT	PPI	. . .[b]	. . .[b]
Treflan	trifluralin	AL	PPI	21	21
Butyrac 200, Butoxone	2,4-DB	AL, CL, BT	Post	60	60
Buctril	bromoxynil	AL	Postfall	60	60
		AL	Postspring	30	30
Gramoxone Extra	paraquat	AL	After cut[c]	30	30
Poast Plus	sethoxydim	AL	Post	7	14
Pursuit	imazethapyr	AL	Post	30	30
Select	clethodim	AL, BT	Post	15	15
Established legumes					
Many	2,4-DB	AL	Post	30	30
Gramoxone Extra	paraquat	AL	After cut[c]	30	30
Poast Plus	sethoxydim	AL	Post	7	14
Pursuit	imazethapyr	AL	Post	30	30
Roundup Ultra	glyphosate	AL, CL, BT	Spot-treat	14	14
Roundup Ultra	glyphosate	AL, CL, BT	Renovate	56	56
Roundup Ultra	glyphosate	AL	Last cutting	7	7
Gramoxone Extra	paraquat	AL	Dormant	60	60
Kerb	pronamide	AL, CL, BT	Dormant	120	120
Lexone	metribuzin	AL	Dormant	28	28
Sencor	metribuzin	AL	Dormant	28	28
Sencor	metribuzin	AL	Predormant/ postdormant[d]	60	60
Select	clethodim	AL, BT	Post	15	15
Sinbar	terbacil	AL	Dormant	. . .[b]	0
Treflan	trifluralin	AL	Dormant or after cutting	21	21
Velpar	hexazinone	AL	Dormant	30	30

[a]AL = alfalfa, CL = clover (red, alsike, or ladino), BT = birdsfoot trefoil, PPI = preplant-incorporated.
[b]No grazing information on label.
[c]Between cuttings (less than 5 days after cut with less than 2 in. regrowth).
[d]If impregnated on dry fertilizer.

weeds may not be a significant problem. Some weeds such as dandelions are palatable and may not require control if the overall legume stand is dense and healthy, but undesirable weeds must be controlled early to prevent their establishment.

Postemergence Herbicides

Poast Plus (sethoxydim) or **Select** (clethodim) may be applied to seedling alfalfa for control of annual and some perennial grass weeds after weed emergence. Grasses are more easily controlled when small. **Butyrac** (2,4-DB) controls many broadleaf weeds and may be applied postemergence in many seedling forage legumes. **Pursuit** (imazethapyr) may be applied postemergence to seedling alfalfa for control of several broadleaf and grass weed species. **Buctril** (bromoxynil) may be used to control broadleaf weeds in seedling alfalfa. Be sure to apply Buctril while weeds are small, and use precautions to avoid an adverse effect on the crop. (See Table 16.08 for specific weed control ratings and Table 16.09 for rates and remarks.)

Established Legumes

The best weed control practice in established forage legumes is maintenance of a dense, healthy stand with proper management techniques. Chemical weed control in established forage legumes is often limited to late fall or early spring applications of herbicide. **Sencor** or **Lexone** (metribuzin), **Sinbar** (terbacil), and **Velpar** (hexazinone) are applied after the last cutting in the fall or in the early spring. These herbicides control many broadleaf weeds and some grasses, too. **Kerb** (pronamide) is used for grass control and is applied in the fall after the last cutting. The herbicide **2,4-DB** controls many broadleaf weeds in established alfalfa; it should be applied when the weeds are small and actively growing. **Pursuit** may be applied postemergence to established alfalfa stands to control certain broadleaf and grass weed species. Refer to Tables 16.08 and 16.09 for additional remarks and weed control suggestions.

Once grass weeds have emerged, they are particularly difficult to control in established alfalfa. **Poast Plus** or **Select** may be used in established alfalfa for postemergence control of annual and some perennial grasses. Optimal grass control is achieved if Poast Plus is applied when grasses are small and before the weeds are mowed.

Table 16.08 outlines current suggestions for weed control options in legume forages. The degree of control often varies with weed size, application rate, and environmental conditions. Select the correct herbicide for the specific weeds to be controlled (Table 16.08). Refer to Table 16.10 for grazing and harvesting restrictions for forage legumes. Always consult the herbicide label for specific information about using a given product.

Authors

A. Hager
Department of Crop Sciences

with contributions by
M. McGlamery
Department of Crop Sciences

Chapter 17.
Management of Field Crop Insect Pests

This chapter focuses on pest management guidelines for insects that attack corn, soybeans, alfalfa, and wheat in Illinois. Practical, *nonchemical control* measures that have proven effective are discussed and strongly encouraged. However, *insecticides* often are the only efficient tool for responding to insect pest outbreaks. We recommend that insecticides be used only to supplement a completely *integrated pest management* (IPM) program that also includes the use of host plant resistance and cultural, mechanical, and biological control tactics.

IPM has been defined as a comprehensive approach to pest control that uses combined methods to reduce pest densities to tolerable levels while maintaining a quality environment. In this context, insecticides should be used only after all other effective insect control alternatives have been considered. Although the use of insecticides has become a standard practice for reducing insect densities, certain problems arise from the sole reliance on insecticides, such as insect resistance to insecticides and threats to the environment and public health. A balanced mix of pest management tactics should avert these types of problems. More than ever, IPM is vital for both a sustainable agriculture and environmental protection.

Scouting and Economic Thresholds

Two principles of an insect management program are scouting fields and basing control decisions on economic thresholds. Growers must understand the importance of these principles and incorporate both regular scouting and the use of economic thresholds into their crop management plans.

A scouting trip through a field reveals which insect pests are present, the stage of growth of the insect pests and the crop, whether the insects are parasitized or diseased, whether an infestation is increasing or decreasing, and the condition of the crop, all of which can be used to determine the need for a control measure. A scouting program also requires accurate, written records of the field location, current field conditions, a history of insect pest infestations and insecticide use, and a map locating infestations. Records enable a grower to keep track of each field and anticipate or diagnose pest problems and crop conditions.

Insect pests can be monitored in several ways. Usually the insects are counted or the amount of crop injury is estimated. Counts of insects commonly are expressed as number per plant, per foot of row, per sweep, or per unit area (square foot or acre). Estimated crop injury usually is expressed as a percentage. Methods of scouting for insects include collecting insects with a sweep net, shaking the crop foliage and counting dislodged insects, counting insects on plants, and capturing insects with traps.

Representative surveys of a field are essential. A field is a unit of land that has been treated the same way agronomically (same planting date, same variety, same crop rotation, same fertility level, etc.). For example, if a 40-acre field has been planted to two corn varieties, 20 acres planted to each variety, the two 20-acre units should be scouted as different fields. Fields should be scouted at least weekly, and inspections should be made in several representative areas of each field. Avoid scouting the edges of a field unless specifically looking for an insect that first invades field edges (grasshoppers, spider mites, stalk borers).

Results from a scouting trip through a field should reveal numbers of insect pests or the percentage of plants that are injured by the pests. A decision to use an insecticide should be made only when an insect population has reached or exceeded an *economic threshold*—that level of a pest population at which control should be implemented to prevent economic loss (that is, the projected cost of damage is greater than the cost of control). Economic thresholds may be expressed as numbers of insects (such as average number of bean leaf beetles per foot of row) or as a level of damage (5 to 10 percent of soybean pods injured within a field).

Environmental and economic conditions are unstable, so several factors may alter an economic threshold: value of the crop (as the price paid for the crop increases, the economic threshold decreases); cost of control (as the cost of control increases, the economic threshold also increases); and crop stress (as the amount of stress on a crop increases, the economic threshold may decrease). For example, an insecticide may be justified economically for an insect pest density that is below the economic threshold if the crop is under stress from a lack of moisture, severe weed pressure, a plant disease, or a lack of proper fertility. Economic thresholds should be adjusted to reflect changes in market prices, cost of control, and crop stress.

Although economic thresholds generally have reduced excessive use of insecticides, economic thresholds do not reflect any of the potential environmental hazards associated with a pesticide treatment, such as reduced densities of beneficial insects, pesticide residues on food products, pesticide contamination of surface and groundwater supplies, and wildlife kills. Before deciding to apply an insecticide, a grower should weigh the risks to human health and safety and environmental risks against the economic benefits. If a particular insecticide poses significant risks to human health or the environment, a grower should select another product or another tactic.

Insect Management Tactics

The judicious use of insecticides is accomplished most often by blending insect control tactics. Insect management programs may include cultural, mechanical, physical, biological, genetic, regulatory, and chemical control methods. Some common tactics used in field crop insect-management programs in Illinois are (1) planting insect-resistant crop varieties; (2) rotating crops; (3) changing tillage practices; (4) altering planting or harvest times; (5) conserving biological control agents; and (6) applying insecticides.

Insect-resistant crops. Certain varieties of field crops offer some level of resistance or tolerance to specific insect pests. For example, conventional breeding efforts have produced corn hybrids with degrees of tolerance or resistance to leaf feeding by first-generation European corn borers and sheath-collar feeding by second-generation borers. Resistant or tolerant varieties also are available for the following insects: corn rootworms in corn; bean leaf beetle, Mexican bean beetle, potato leafhopper, and twospotted spider mite in soybeans; Hessian fly in wheat; and alfalfa weevil, aphids, and potato leafhopper in alfalfa.

Recent developments in genetic engineering have produced crop varieties that impart resistance to insect pests. Specifically, gene transfer techniques have been used to produce corn plants that contain a gene taken from the bacterium *Bacillus thuringiensis*, often abbreviated as *Bt*. The *Bt* gene has been inserted directly into the corn genome. The gene produces a crystal protein that is toxic to certain caterpillars, including the European corn borer and southwestern corn borer. After the caterpillar ingests the protein, the crystal breaks down and releases a toxin that attacks the gut lining. The insects stop feeding within a few hours and die within a couple of days. The presence of this *Bt* toxin in corn provides season-long protection against European corn borers and southwestern corn borers and some protection against corn earworms and stalk borers. "*Bt*-corn" offers an opportunity to control one of our most economically damaging corn insect pests without the use of conventional insecticides. Biotechnology likely will continue to produce crop hybrids that are resistant to many of our most important insect pests of field crops.

As a first step in managing insect pests in field crops, consider resistance or tolerance when selecting a crop variety. At the very least, solicit from the seed dealer information about the variety selected and its ability to resist or tolerate insect infestations.

Crop rotation. Crop rotation greatly influences whether a soil insect problem may occur. The complex of insect pests changes according to the types of crops rotated, the sequence of the crop rotation, and the amount of time devoted to the production of a particular crop before planting a new crop. The brief summaries that follow should help producers determine the likelihood of an insect outbreak in different crop rotation schemes.

Corn after soybeans. The potential for soil insect problems in corn after soybeans generally is low, and the use of a soil insecticide typically is not recommended. This recommendation remains true for all areas of Illinois except east-central Illinois where western corn rootworm larvae recently have injured roots in fields of corn planted after soybeans (see "Corn rootworms" on page 216).

Corn after corn. The potential for rootworm damage exists wherever corn is planted after corn in Illinois. Rootworm soil insecticides are applied to approximately 90 percent of continuous corn acreage, even though economic infestations generally occur in only half of all continuous corn fields.

Corn after legumes. Cutworms, grape colaspis, white grubs, and wireworms occasionally damage corn planted after clover or alfalfa. Adult northern corn rootworms sometimes are attracted to legumes or to weed blossoms in legumes for egg laying, especially in years when beetles are forced to leave adjacent

fields of drought-stressed corn to seek food. The use of a seed treatment is recommended, but producers may consider the use of a soil insecticide for this cropping sequence.

Corn after small grain. There is a slight potential for injury caused by wireworms, seedcorn beetles, and seedcorn maggots in corn after small grain, particularly wheat. In most instances, a diazinon + lindane planter-box seed treatment is adequate. However, excessive weed cover in small-grain stubble may have been attractive to northern corn rootworm beetles for egg laying if the adults moved from adjacent fields of drought-stressed corn.

Corn after grass sod. Corn billbugs, sod webworms, white grubs, and wireworms may cause stand reductions when corn is planted after bluegrass, brome, fescue, rye, or wheat. If a producer plants corn into an established field of grass sod, an insecticide, applied either before or at planting, should be considered for the control of wireworms and white grubs. Rescue treatments applied after the damage is noticed are not effective. If a stand is being thinned severely by wireworms or white grubs, the only options are to accept the reduced stand or replant and apply an insecticide during replanting.

Corn after sorghum. A planter-box seed treatment of diazinon or diazinon + lindane will protect the seeds from seedcorn maggots.

Tillage. The type of equipment and the timing (fall or spring), depth, and frequency of tillage operations can influence the survival of some insect species. Tillage operations may alter soil temperature, soil moisture, aeration, organic matter content, and bulk density of the soil, each of which may have a direct effect on some insects' survival and development. Often of greater importance to an insect population are the indirect effects occasionally associated with certain tillage systems. For example, poor weed control in some tillage systems increases the potential for infestation of some insects (black cutworms, stalk borers). However, sweeping predictions about how all insects respond to a certain tillage practice are not appropriate.

Insects that may cause problems in mulch-till, ridge-till, or no-till corn can be divided into two categories: soil insects and foliage-feeding insects. Soil insects include billbugs, corn rootworm larvae, cutworms, seedcorn beetles, seedcorn maggots, white grubs, and wireworms. Foliage-feeding insects include armyworms, brown and onespotted stink bugs, European corn borers, and stalk borers.

The insects most affected by changes in tillage practices are those that overwinter in the soil and become active during the early stages of crop growth. Soil- and litter-dwelling insects are affected more than the foliage-feeding insects. In most instances, a greater diversity of insects is present in reduced-tillage systems, but this greater diversity does not always result in predictable increases or decreases in crop injury because both pests and their natural enemies respond to tillage practices.

Much less is known about the influence of various cultural practices on insects in soybeans. Most soybean insect pests are defoliators or pod feeders. They often are very mobile; some immigrate from other regions of the country, and most move readily from field to field. The effect of a single soybean producer's tillage practices on the potential for injury caused by defoliators is insignificant. However, slugs, which are not insects, occasionally cause significant injury to no-till soybeans. Densities of slugs are often highest in no-till systems where crop residue is greatest; their densities are lowest where no residue is present. Due to the residue cover and inclusion of soybeans in no-till rotational systems, slug problems are expected to increase as conservation tillage becomes more common.

Altering planting or harvest times. The time of planting influences the development of infestations of several pests on several crops. For example, European corn borer moths laying eggs for the first generation are attracted to fields with the tallest corn. Consequently, corn that is planted early should be monitored closely during June and early July for signs of whorl feeding by corn borer larvae. However, late-planted corn fields are most susceptible to economic infestations of the second generation of corn borers.

The time of planting corn also affects the potential for infestation by black cutworms and corn rootworms. Early planted corn usually escapes infestations by black cutworms but supports infestations by corn rootworm larvae. Late-planted corn is more likely to be attacked by black cutworms but may escape severe root-feeding injury caused by rootworm larvae. However, late-planted corn also attracts egg-laying rootworm beetles late in the season, which increases the potential for larval injury the next year.

For some specific insect pests, altering planting or harvest dates can be used as a management tactic without adversely affecting crop performance. For example, wheat can be planted after "fly-free dates" to control Hessian fly (see "Hessian fly" on page 225), and alfalfa can be harvested early to manage alfalfa weevils or potato leafhoppers.

Biological control. Certain insects and diseases naturally suppress populations of pest insects without our help. For example, European corn borer densities are often reduced by *Beauvaria bassiana*, a fungus, or by *Nosema pyrausta*, a protozoan. Natural control by predators, parasitoids, and pathogens may alter pest-

management decisions. An abundance of predators or parasitoids or a significant percentage of diseased pests may suggest that an insecticide application is not necessary. Producers should make every effort to conserve natural enemies by avoiding unnecessary applications of insecticides.

Through a process called *applied biological control,* predators, parasitoids, or disease pathogens are introduced into a field. Although considerable research has been conducted, the introduction of beneficial insects and disease pathogens into corn and soybean fields to control pest insects has not been very effective. Field crop environments change constantly, so beneficial organisms have a difficult time becoming established.

The use of microbial insecticides offers more potential within an IPM program. Microbial insecticides are made of microscopic living organisms (viruses, bacteria, fungi, protozoa, or nematodes) or the toxins produced by them. These insecticides can be formulated to be applied as sprays, dusts, or granules. Their chief advantage is an extremely low toxicity to nontarget animals and humans. The most familiar microbial insecticides (DiPel and similar products) are those that contain toxins produced by *Bacillus thuringiensis.*

Applying insecticides. Insecticides should be used only after all other effective insect control alternatives have been explored. The decision to use an insecticide should be based upon (1) information obtained from scouting; (2) knowledge of economic thresholds; and (3) an awareness of the potential benefits and risks associated with a treatment. If used improperly, insecticides can cause detrimental effects to the applicator, the crop, or the environment. Insecticides can provide effective control, but they should be used judiciously and in combination with nonchemical methods that can be incorporated into the cropping system. After a decision to use an insecticide has been made, several aspects of the insecticide should be considered: Is it labeled for control of the target insect? Is it effective against the target insect? What is the rate of application? How toxic is the insecticide? Is it classified as general use or restricted use? What environmental hazards are posed by use of the insecticide? What human health hazards are posed by use of the insecticide? Answers to these questions will help producers select the most appropriate insecticide for the use intended and the current conditions.

Key Field Crop Insect Pests

This section contains discussions of some of the key insect pests in field crops in Illinois, including descriptions, life cycles, current economic thresholds, and current management suggestions. However, a complete list of insecticides that can be used to control all of the potential insect pests has not been included. Tables that provide specific information about insecticides and their use for all of the insect pests that attack corn, soybeans, alfalfa, grain sorghum, small grains, and pasture are published in Chapter 1, "Insect Pest Management for Field and Forage Crops," in the current year's edition of the *Illinois Agricultural Pest Management Handbook.* Color photographs and more information about scouting are published in the *Field Crop Scouting Manual.*

Insect Pests of Alfalfa

Due to its lush growth, alfalfa is an excellent habitat for many insects: species destructive to alfalfa and other crops; species that inhabit the alfalfa but have little or no effect on the crop; pollinating insects; incidental visitors; and predators and parasitoids of other insects. Many species overwinter in alfalfa because it grows perenially.

More than a hundred species of insects and mites are capable of reducing alfalfa yield, impairing forage quality, or reducing the vitality and longevity of the crop. However, only two insect species are considered key pests: the alfalfa weevil and the potato leafhopper.

Alfalfa weevil

Description. The mature alfalfa weevil larva is about ⅜ inch long and has a black head. The curved body of the larva is green, with a white stripe along the center of the back. The adult alfalfa weevil is about ¼ inch long and has a distinct snout. It is light brown, with a darker brown stripe along the center of the back.

Life cycle and damage. In southern Illinois, when temperatures permit, adult weevils lay eggs throughout the fall and winter and into the spring. Because eggs begin to hatch about the time alfalfa is beginning its spring growth, larval injury occurs early in the spring. In northern Illinois, most eggs are deposited in the spring. By the time larvae emerge, alfalfa is usually 6 to 10 inches tall and can tolerate more weevil feeding than the southern crop.

Newly hatched larvae feed in the growing tips. An early sign of injury is pinholes in newly opened leaves. As larvae grow larger, they shred and skeletonize the leaves. Heavily infested fields appear frosted because of the loss of green leaf tissue. Anything that slows spring alfalfa growth increases the impact of weevil injury.

When weevil larvae finish feeding, they spin netlike cocoons on the plants or in soil debris and pupate. After several days, the adults emerge and feed on alfalfa for a few weeks. They cause leaves to appear "feathered," and they scar the stems of the alfalfa

plants. In addition, both surviving larvae and newly emerged adults may affect regrowth after the first cutting. They remove early shoot growth, depleting food reserves in the roots and reducing the stand.

The adults eventually leave alfalfa fields to enter summer dormancy in sheltered sites. In the fall, most adults return to alfalfa, where they feed for a while before "hibernating." In southern counties, the adults mate and lay eggs, and both adults and eggs overwinter. Alfalfa weevils complete one generation each year.

Management suggestions. The key to effective management of alfalfa weevils is timely monitoring. Growers in southern and central Illinois should inspect their fields closely in April, May, and June. Growers in northern counties should look carefully for larval injury during May and June. All growers should examine the stubble after the first cutting of alfalfa has been removed. Treatment for control of alfalfa weevils on the first crop of alfalfa may be warranted when there are 3 or more larvae per stem and 25 to 50 percent of the tips have been skeletonized, depending on the height of the crop and the vigor of growth. Tall, rapidly growing alfalfa can tolerate considerable defoliation without a subsequent loss in yield. After harvest, control may be warranted when larvae and adults are feeding on more than 50 percent of the crowns and regrowth is prevented for three to six days.

Parasitic wasps and a fungal disease may regulate alfalfa weevil populations in the spring. When scouting for alfalfa weevils, look for signs of parasitism and for diseased weevils (discolored, moving slowly, or moving not at all). When natural enemies and pathogens suppress weevil numbers, insecticide treatments may not be necessary.

Potato leafhopper

Description. The adult potato leafhopper is a green, wedge-shaped insect about ⅛ inch long. Nymphs resemble the adults but are smaller and wingless. Both have piercing, sucking mouthparts and are very active. The adults hop or fly, and the nymphs move rapidly, either sideways or backward, when disturbed.

Life cycle and damage. Potato leafhoppers do not overwinter in Illinois. Prevailing spring winds carry adults northward from the Gulf Coast states, and leafhoppers first appear in alfalfa fields in Illinois in late April or early May. The adults mate and begin laying eggs in stems and leaf veins. Nymphs emerge in about a week and begin feeding. Several generations may occur before cold temperatures kill the leafhoppers.

Both nymphs and adults suck fluids from alfalfa plants. Nymphs cause more damage than adults. Initial injury is characterized by a V-shaped yellow area at the tips of the leaflets, often called "hopperburn" or "tipburn." As the injury progresses, the leaves turn completely yellow and may turn purple or brown and die. Severely injured plants are stunted and bushy. Leafhopper injury also causes plants to produce more sugars and less protein and vitamin A, resulting in lower-quality alfalfa. If leafhoppers deplete root reserves of the late-season growth of alfalfa, the plants will be less hardy and may not survive the winter.

Injury by potato leafhoppers often is confused with boron deficiency, plant diseases, or herbicide injury. The presence of the insect often is the key to diagnosing the problem.

Management suggestions. Sampling with a 15-inch-diameter sweep net is the best method for monitoring populations of potato leafhoppers in alfalfa. Economic thresholds are based on the number of leafhoppers per sweep of the sweep net.

When alfalfa is regrowing after a cutting, scouting for leafhoppers is critical. Tender, regrowing alfalfa is very susceptible to leafhopper injury. Taller, more mature alfalfa can tolerate more leafhopper injury, and the economic thresholds vary accordingly. An insecticide may be warranted for alfalfa up to 3 inches tall when there is an average of 0.2 leafhopper per sweep. The economic thresholds for 3- to 6-inch alfalfa, 6- to 12-inch alfalfa, and alfalfa taller than 12 inches are 0.5, 1, and 2 leafhoppers per sweep, respectively.

Sampling is very important. By the time symptoms of potato leafhopper injury appear, considerable yield and nutritional quality may have been lost. Monitoring should begin after first harvest and continue on a regular basis throughout the summer.

Within the past couple of years, some seed companies have released glandular-haired alfalfa that is resistant to potato leafhoppers. Glandular-haired alfalfa seems to be resistant to moderate densities of leafhoppers. However, it does not seem to prevent leafhopper infestations during the first year of seeding, during seedling regrowth immediately after cutting, or during years when leafhopper infestations are severe. The overall utility of these resistant alfalfa varieties has yet to be determined.

Insect Pests of Corn

Insects that attack corn generally are separated into two categories: those that attack the plant below ground and those that attack the plant above ground. Populations of below-ground insects are difficult to predict; responsive "rescue" treatments are ineffective for most. Consequently, many corn producers prevent infestations with crop rotation or application of soil insecticides. A list of soil insecticides that are suggested for control of corn rootworms, cutworms, wireworms, and white grubs is presented in Table 17.01.

Table 17.01. Insecticides Suggested for Control of Some Soil Insects in Illinois

Insecticide	Rootworms	Cutworms	Wireworms	White grubs
*Ambush 2E	—	•	—	—
*Asana XL	—	•	—	—
*Aztec 2.1G	•	•	•	•
*Counter CR	•	—	•	•
*Force 3G	•	•	•	•
*Fortress 5G[a]	•	•	•	•
Lorsban 15G	•	•	—	—
Lorsban 4E	—	•	•	•
*Pounce 1.5G	—	•	—	—
*Pounce 3.2EC	—	•	—	—
*Regent 4SC	•	—	•	•
*Thimet 20G	•	—	•	•
*Warrior 1EC	—	•	—	—
*Warrior T	—	•	—	—

* Use restricted to certified applicators only.
— = The most economical rate and application of this insecticide is not labeled for control of this insect, or labeled only for suppression or aid in control of the insect.
• = The most economical rate and application of this insecticide is labeled for control of this insect. Refer to label for rate, timing, and placement of application.
[a]Available only in the SMARTBOX, a closed handling and application system.

Most *below-ground insect pests* in Illinois feed on underground parts of the corn plants. Corn rootworm larvae feed on and prune the roots; white grubs and grape colaspis larvae feed on the root hairs and the roots; wireworms, seedcorn beetles, and seedcorn maggots attack the planted seeds; wireworms also will tunnel into the underground portion of the stem. Young cutworms feed on the leaves of seedling corn plants; older cutworms cut off the plants at, just below, or just above the soil surface. Webworms cause injury similar to that caused by cutworms. Hop vine borers drill into the underground portion of the stem and tunnel upward. Billbugs and stink bugs feed at the bases of the cornstalks; billbug larvae feed inside the lower portion of the stalk.

Above-ground insect pests include stalk-boring insects such as the European corn borer, southwestern corn borer (southern Illinois), and stalk borer, and insects that feed primarily on the leaves, such as armyworms, fall armyworms, flea beetles, and grasshoppers. Chinch bugs, corn leaf aphids, spider mites, and thrips suck the fluids from the plants at different times of the growing season. Corn rootworm beetles, Japanese beetles, and woollybear caterpillars clip corn silks, interfering with pollination. Larvae of corn earworms, European corn borers, and fall armyworms feed on the ear.

Black cutworm

Black cutworms occur sporadically as pests of corn in Illinois. When an outbreak develops, however, the resulting damage may be extensive. Black cutworms feed on seedling corn, which is very susceptible to any type of injury.

Description. Black cutworm larvae vary in color from light gray to black, and are about 1½ inches long when fully grown. Numerous convex skin granules of different sizes give the cutworm a somewhat "greasy" and rough appearance. The moths (adults) have a robust body and a wingspan of about 1½ inches. They are dark gray, with a black, dagger-shaped marking toward the outer edge of the forewing.

Life cycle and damage. Black cutworms probably do not overwinter in large numbers in Illinois. Evidence suggests that the moths fly into the Midwest from southern states early in the spring. Some people use sticky traps baited with synthetic female sex pheromone to monitor moth flight in the spring. Results from trap captures may help timing of insecticide applications, if necessary.

Female moths lay eggs primarily on weedy vegetation, preferably on winter annuals. After the eggs hatch, the small larvae feed on these host plants. When herbicides or tillage destroys the weeds, the larvae begin feeding on corn seedlings.

The larvae pass through six or seven instars (stages of larval development). Their rate of development depends upon temperature: the larvae develop more quickly when the weather is warm. The first three instars are very small, and the larvae feed on the corn leaves. This injury, which is not economic, appears as small holes or bites in the leaves. The fourth through seventh instars cut the plants off at or just below the soil surface. If the soil is dry and crusted, the larvae remain below the surface and drill into the base of the plant. If the growing point is destroyed or the plant is cut below the growing point, the plant will not survive. Large numbers of black cutworms can drastically reduce the plant population in a field.

After the larvae finish feeding, they pupate. The moths then emerge from the soil and begin mating and laying eggs for the next generation. There may be three or four generations each year, but the later generations rarely injure taller corn.

Management suggestions. Although some growers apply soil insecticides to prevent an infestation of black cutworms, it usually is not justified economically. Because black cutworm populations are so sporadic and difficult to predict, a wait-and-see approach to cutworm management is recommended.

Field monitoring is the key to effective management of black cutworms. To determine the need for a rescue treatment, scout the fields during plant emergence, particularly those considered to be at high risk. Check the field for leaf feeding, cut plants, wilted plants, and missing plants. A rescue treatment may be warranted if 3 percent or more of the plants are cut and cutworms are present. A single cutworm will cut three or four plants if the plants are in the two-leaf stage or smaller. After corn plants reach the four-leaf stage, a single cutworm will cut only one or two plants during the remainder of its larval stage.

Control of cutworms may be poor regardless of the insecticide used if the topsoil is dry and crusted and the worms are feeding below the soil surface. Cutworm control may be enhanced by cultivating or running a rotary hoe over the field before or after spraying. This disruption causes the worms to move around and come into contact with the insecticide. Insecticides registered for control of black cutworms are presented in Table 17.01.

Corn rootworms

Corn rootworms are the most economically important pests of corn in Illinois. Corn rootworms include three species: western, northern, and southern. Southern corn rootworms do not overwinter in the Midwest, however, so the western and northern species are the only injurious species in Illinois.

Description. The background color for both male and female western corn rootworms is yellow-tan, but the two sexes differ somewhat in their markings. On males, nearly the entire front half of each wing cover is black; only the tips of the wing covers are yellow-tan. Females are slightly larger and have three distinct black stripes on the wing covers, one near each outer edge and one in the middle. Northern corn rootworms have no distinct markings. Newly emerged northern corn rootworms are cream or tan in color, but they become green as they age. Both species are about ¼ inch long. The larvae of both species are creamy white with a brown head and tail plate.

Life cycle and damage. Western and northern corn rootworms overwinter as eggs in the soil. Eggs begin hatching in May. If corn has been planted in the field, the larvae feed on the roots. Rootworms survive only on the roots of corn and a few grasses. They cannot survive on the roots of soybeans and other broadleaf plants.

Larvae chew on and tunnel inside or along the roots. As they feed, the larvae prune roots back to the stalk. Extensive feeding weakens the root system. Injured plants cannot take up water and nutrients efficiently and are susceptible to lodging. Yield losses are a result of both root pruning and lodging.

When the larvae finish feeding, they pupate within small earthen cells. The pupa transforms into the adult stage in about one week, and beetles begin emerging in late June or early July.

Rootworm beetles will feed on corn leaves and weed blossoms but prefer corn silks and pollen. They clip fresh, green silks off at the ear tip, an injury that may interfere with pollination, so some kernels never form. An average of 5 or more beetles per plant is usually sufficient to cause economic damage if they are clipping silks to within ½ inch of the ear tip.

Beetles mate in July and August, and the females lay eggs in cornfields in the top 4 inches of soil. Western and northern corn rootworms complete one generation each year.

Management suggestions. A *corn-soybean rotation* usually provides excellent control of corn rootworm larvae because the larvae survive only on corn roots; rootworms complete only one generation each year; and rootworm beetles, except for western corn rootworm adults in east-central Illinois, generally do not lay eggs in soybeans. A corn-soybean rotation may fail to control corn rootworms when volunteer corn plants in a soybean field attract egg-laying beetles or when rootworms exhibit prolonged diapause, a biological phenomenon that allows some rootworm eggs, primarily those of northern corn rootworms, to remain dormant in the soil for more than one winter.

Also, in some east-central Illinois counties, western corn rootworms have adapted to a corn-soybean rotation and are prone to lay eggs in both soybeans and corn.

Since 1993 the incidence and severity of corn rootworm larval injury in first-year corn fields (primarily corn rotated with soybeans) throughout much of east-central Illinois have increased. Producers in the following counties have been affected most often: Champaign, Ford, Grundy, Iroquois, Kankakee, Livingston, McLean, Vermilion, and Will. Producers in the following counties may be at some risk: Clark, Coles, DeWitt, Douglas, Edgar, Kendall, LaSalle, Logan, Macon, Moultrie, Peoria, Piatt, and Woodford. Growers throughout the northern half of Indiana and in southern Michigan and western Ohio also have reported similar rootworm problems in corn rotated with soybeans.

Producers in east-central Illinois who have experienced rootworm larval injury in first-year corn and have found western corn rootworm adults in adjacent soybean fields should consider using a soil insecticide in corn rotated with soybeans. An economic threshold for adult western corn rootworms in soybeans has been developed to help producers determine whether a soil insecticide is needed to protect corn the next year. Growers can sample for western corn rootworm adults by placing 12 unbaited Pherocon AM traps (yellow sticky traps) systematically throughout the interior of a soybean field. If the number of western corn rootworm adults from the last week of July through the third week of August exceeds an average of two to seven beetles per trap per day, economic damage caused by larvae to corn roots the next year is likely. The lower threshold (two beetles per trap per day) suggests a level of root injury that may be economic. The higher threshold (seven beetles per trap per day) suggests a level of root injury that likely will be economic. A planting-time application of a soil insecticide to corn should be considered if numbers of western corn rootworm adults exceed one or the other of these thresholds in soybeans during the previous summer. More detailed information about western corn rootworms is provided in *Insect Information 1: Western Corn Rootworm*, a fact sheet published by the Department of Crop Sciences at the University of Illinois. The fact sheet is also available on the Web at <http://www.aces.uiuc.edu/~ipm/field/corn/insect/wcr.html>.

Growers outside of east-central Illinois are encouraged not to use a soil insecticide on first-year corn for rootworm control. As of 1998, the new "strain" of western corn rootworm had not been detected in counties other than the 22 mentioned previously.

Corn planted after corn is susceptible to injury by corn rootworm larvae, depending upon the size of the rootworm population. Most producers who grow corn after corn usually apply a soil insecticide at planting to protect the corn roots from larval-feeding injury. Most growers apply granular insecticides in either a 7-inch band directly over the row or directly into the seed furrow (Tables 17.01 and 17.02). Some liquid formulations of soil insecticides are also labeled for control of corn rootworm larvae (Tables 17.01 and 17.02). Trials conducted by entomologists at the University of Illinois have revealed that Aztec, Counter, Force, and Lorsban provide the most consistent control of corn rootworm larvae.

By counting western and northern corn rootworm beetles from mid-July into September, growers can figure out the potential for rootworm larval injury the following year. If the average is 0.75 or more beetles per corn plant for any sampling date, plan to rotate to a nonhost crop, or apply a rootworm insecticide if corn will be planted the following year. If the average is fewer than 0.75 beetle per corn plant, the probability of economic damage the next year is low, and a soil insecticide is not necessary.

Another corn rootworm management tactic is to control the adults in July or August or both months to prevent them from laying eggs. If this tactic works, a soil insecticide is not needed the following year. Both conventional insecticides and insecticide baits are used to control the beetles before they lay eggs. However, the prerequisites for a successful beetle-suppression program are complex. It is necessary to identify both species (western and northern), distinguish between the sexes, and determine whether the females are ready to lay eggs. Frequent scouting trips and precise scouting techniques also are required.

An adult management approach to prevent egg laying by western corn rootworms in soybeans currently is not recommended. Until sampling strategies and economic thresholds can be developed, growers are encouraged not to attempt this strategy to prevent corn rootworm larval injury in corn planted after soybeans.

Spraying to kill adult western corn rootworms in soybeans one year and also treating corn with a soil insecticide to control larvae the next year is strongly discouraged. Treating two stages (adults and larvae) of the same insect is a quick way to develop insecticide resistance within the insect population.

Planning your rootworm management program. A management plan for rootworms should be long-range (not a year at a time) and include crop rotation, soil insecticides if needed, and scouting to determine the need for rootworm control.

Table 17.02. Soil Insecticides for Rootworm Control in Illinois, 1999

Insecticide	Time of application	Oz of product per 1,000 ft of row	Amount of product per acre[a]			
			40" rows	38" rows	36" rows	30" rows
*Aztec 2.1G	At planting	6.7	5.5 lb	5.8 lb	6.1 lb	7.3 lb
Counter CR	At planting or cultivation	6	4.9 lb	5.2 lb	5.4 lb	6.5 lb
*Force 3G	At planting	4–5	3.3–4.1 lb	3.4–4.3 lb	3.6–4.5 lb	4.4–5.5 lb
*Fortress 5G[b]	At planting	3	2.5 lb	2.6 lb	2.75 lb	3.25 lb
*Furadan 4F	At cultivation	2.5 fl oz	2 pt	2⅛ pt	2¼pt	2¾pt
Lorsban 15G	At planting or cultivation	8	6.5 lb	6.9 lb	7.3 lb	8.7 lb
Lorsban 4E	At cultivation	2.5 fl oz	2 pt	2⅛ pt	2¼ pt	2¾ pt
*Regent 4SC	At planting	0.24 oz	3.1 oz	3.3 oz	3.5 oz	4.2 oz
*Thimet 20G	At planting or cultivation	6	4.9 lb	5.2 lb	5.4 lb	6.5 lb

* Use restricted to certified applicators only.
[a] Do not exceed the following amounts of specific products per acre per season: 7.3 lb of Aztec 2.1G; 6.5 lb of Counter CR; 13.5 lb of Lorsban 15G; 4.2 oz of Regent 4SC. The minimum row spacing of corn to which Thimet 20G can be applied is 30 in.
[b] Available only in the SMARTBOX, a closed handling and application system.

- Alternate corn with another crop when possible, particularly in fields where rootworm beetles averaged 0.75 or more per corn plant last summer, or if the soil insecticide did not adequately protect the roots during the previous growing season.
- If the plan is to grow corn after corn and if rootworm beetles averaged 0.75 or more per plant in corn after corn or 0.5 per plant in first-year corn last summer, apply a rootworm soil insecticide at planting time.
- If the plan is to grow corn after soybeans in east-central Illinois and if rootworm beetles averaged two to seven or more per yellow sticky trap per day in soybeans last summer, apply a rootworm soil insecticide at planting time.
- Consider a cultivation-time application of a rootworm soil insecticide if the intent is to plant in early April or if the planting-time insecticide does not provide adequate root protection.
- Scout for rootworm beetles from mid-July through early September to determine the potential for rootworm larval damage for the next growing season.

Other soil insects in corn

In addition to corn rootworms and black cutworms, several other insects attack the underground portions of the corn plant early in the season. Wireworms and seedcorn maggots occasionally injure seeds and seedlings. White grubs and grape colaspis larvae feed on the roots. Other insects—including billbugs, other species of cutworms, and webworms—feed on corn seedlings at or just above or below the soil surface.

Wireworms. Most wireworm larvae are yellowish or reddish brown, hard-shelled, and wirelike. However, "soft-bodied" species are creamy white except for a reddish brown head and tail section. Wireworms attack the seed or drill into the base of the stem below ground, damaging or killing the growing point. Above-ground symptoms are wilted, dead, or weakened plants and spotty stands. Several species of wireworms attack corn, and they may live for 2 to 5 years in the larval stage.

The adults (click beetles) prefer to lay eggs in grassy fields or small-grain stubble. Injury in a field in a particular year usually can be attributed to the condition of the field two to four years earlier when the adults were laying eggs. Fields with a corn–soybean–small-grain rotation and fields of corn planted after sod have the greatest potential for wireworm damage.

Although wireworm infestations are difficult to predict, solar bait stations will trap wireworm larvae early in the spring. Establish bait stations early in the spring by placing a mixture of corn and wheat seed in a 4- to 6-inch hole in the ground, covering the seeds with soil, then covering the soil with plastic. The plastic warms the soil and induces germination. Wireworm larvae are attracted to the germinating seeds. After the baits have been in the ground for 10 to 14 days, dig them up and count the wireworms. An average of one or more wireworms per bait station sug-

gests that an economically damaging population is present in the field. The grower can apply a soil insecticide that controls wireworms.

White grubs. True white grubs have 3-year life cycles. Peak levels of injury usually occur during the year following large flights of May beetles, the adult stage of white grubs. The beetles prefer to lay eggs in ground covered with vegetation, for example, weedy soybean fields, and sod. At least one species lays its eggs in soybean fields.

The C-shaped white grub has a brown head and is about an inch long. The grubs chew on the roots and root hairs. Symptoms of white grub injury visible above ground are irregular emergence, reduced stands, and stunted or wilted plants. Injured plants often cannot take up phosphorus efficiently, so the plants may turn purple. Injury is generally spotty throughout the field.

Rescue treatments applied after injury caused by wireworms or white grubs are not effective. An insecticide seed treatment protects the seed from attack by wireworms but does not protect the seedling plant from wireworms and white grubs.

Several soil insecticides are registered for the control of wireworms and white grubs (Table 17.01). The percentage of fields affected in Illinois is so small, however, that the widespread use of soil insecticides to prevent injury by these pests is not justified economically.

European corn borer

The European corn borer is one of the most destructive pests of corn in the United States. The larvae tunnel inside the corn plants and disrupt the flow of water and nutrients to the developing ear. Extensive tunneling may cause stalks to break or lodge. Tunneling in the ear shank may result in ear drop. Corn borer feeding also provides an avenue into the plant for infection by stalk-rot organisms.

Description. Corn borer larvae are cream- to flesh-colored, with small, raised, dark spots (tubercles) on each body segment. The head is dark brown. Full-grown larvae are ¾ to 1 inch long. The female moth is buff-colored, with wavy, olive-brown bands on the wings and a wingspan of an inch. The male moth is slightly smaller and darker than the female.

Life cycle and damage. Two or three generations of European corn borers occur every year, depending upon the location in the state and the weather. The third generation is most common in southern Illinois. European corn borers overwinter as mature larvae, usually inside the stalk. Spring development starts when temperatures exceed 50°F. The larvae begin pupating in May, spend about two weeks in the pupal stage, and emerge as moths in late May and June.

Moths laying eggs for the first generation seek the tallest (earliest planted) corn. The female lays eggs in masses on the undersides of corn leaves near the midrib. Each mass contains 15 to 30 eggs (average 23) that are flat and overlapping like the scales of a fish. During development, the eggs change from white to a creamy color. Immediately before hatching, the black heads of the larvae are visible through the shells.

After the eggs hatch, the tiny larvae begin to feed on the leaf surfaces on their way to the whorl. The small feeding scars look like "window panes." Their feeding in the whorl results in "shot holes" in the leaves. By the third stage (instar) of development, the larvae begin tunneling into the leaf midribs; the fourth and fifth (last) stages bore into the stalks. When they finish feeding, the larvae pupate inside the stalk. Transformation to the adult (moth) stage occurs within the pupa, then the moth emerges to mate and lay eggs. Corn borers require three to four weeks to develop from egg to adult.

Moths laying eggs for the second generation seek later-maturing fields with fresh pollen and silks. They usually deposit their eggs on the undersides of leaves between the ear zone and the tassel. Newly hatched larvae feed primarily on leaf-collar tissue and pollen that accumulates in the leaf-collar areas. More mature larvae tunnel into the stalks, ear shanks, and ears.

Injury to corn by first-generation larvae is primarily physiological. The yield loss caused by this generation is a result of interference with the transport of nutrients and water in the stalk and leaves. Injury by the second generation is both physiological and physical. Most of the yield loss is caused by second-generation corn borers feeding in the stalks from just before pollination until the ears are filled. Stalk breakage, ear feeding, and ear drop also contribute to yield reduction. Physical damage is amplified when stalk rot weakens the plant.

Managing corn borers with Bt-*corn.* As a first step in managing European corn borers, growers should consider selecting a hybrid that is resistant or tolerant. Some "conventional" hybrids are resistant to first-generation corn borers, and others have some degree of tolerance to corn borer injury. Genetically transformed hybrids that express the *Bt* gene (*Bt*-corn) that produces the toxic protein should provide season-long control of European corn borers. (See the section on "Insect resistant crops.") However, the decision to plant *Bt*-corn hybrids should be based on long-term economic benefits, accompanied by considerations for managing the potential for the development of corn borer resistance to the *Bt* gene.

Economic benefits of *Bt*-corn will be realized only during years when densities of corn borers are large

enough to cause economic yield loss. In years when corn borers occur in subeconomic numbers, producers will not realize an economic return on their investment in *Bt*-corn. Therefore, growers must base their decision to manage corn borers with *Bt*-corn on the frequency of economic infestations of corn borers in their area. In areas where economic infestations of corn borers are relatively frequent (for example, 7 or 8 years out of 10), *Bt*-corn is probably a wise investment. In areas where economic infestations of corn borers are relatively infrequent (for example, 2 or 3 years out of 10), growers should question whether purchasing and planting *Bt*-corn is necessary.

If corn hybrids containing a *Bt* protein are planted widely, European corn borer populations eventually will develop resistance to this very specific insect toxin. Consequently, producers who grow *Bt*-corn should implement a resistance-management plan to slow down the potential onset of resistance. Refuges where corn borers are not exposed to the *Bt* toxin are the most practical resistance-management tactic. In theory, high doses of the *Bt* toxin in *Bt*-corn will kill virtually 100 percent of the corn borers. However, if any borers survive in *Bt*-corn, you want to ensure that the surviving adults will mate with adults from areas in which the borers are still susceptible to the *Bt* toxin. These refuges should provide the source of susceptible corn borers.

Refuges include all fields of non-*Bt*-corn and the more than 200 species of plants (including several crops and weeds) on which corn borers can develop. However, resistance-management strategies most often are based upon managed refuges, including entire fields planted to non-*Bt*-corn specifically to provide a source of susceptible corn borers. Alternatives include planting a block of non-*Bt*-corn within a field of *Bt*-corn or planting non-*Bt*-corn in a designated percentage of rows throughout the field.

Refuge fields should be adjacent to fields of *Bt*-corn, and an in-field refuge should make up at least 25 percent of the field. Consult current published insect management recommendations and newsletters to obtain more specific recommendations for implementing resistance-management tactics. North Central Regional Extension Publication NCR 602, Bt-*Corn and European Corn Borer: Long-Term Success Through Resistance Management*, provides a detailed discussion about this management strategy for corn borers.

Managing corn borers with insecticides. Management of European corn borers in conventional hybrids begins with scouting. Scout for first-generation corn borers and injury during June. The percentage of plants with whorl feeding and the average number of larvae per infested plant are critical. Borers can be located by unrolling the whorls of several plants.

Scout for second-generation corn borers by counting egg masses. Start checking when moth flight is under way, usually from July through mid-August.

Entomologists have developed management worksheets for both first- and second-generation European borers to aid in making decisions about control. See the worksheets provided. The level of infestation (obtained from scouting), the expected yield, the anticipated value of the grain, and the cost of control are required to complete the worksheet. Enter these data into the worksheet to calculate the gain or loss if an insecticide is applied.

For example, assume a 40 percent infestation (40 of 100 plants with whorl-feeding injury caused by first-generation borers) of early whorl-stage corn, with an average of 1.5 corn borer larvae per plant. Expected yield is 160 bushels per acre, and the corn price is $2.50 per bushel. Also assume 80 percent control with granules and cost of control is $12 per acre. Enter this information into the worksheet for first-generation corn borers, as indicated on the example worksheet. Obviously, 40 percent infestation in this example does not warrant a treatment ($9.60 per acre preventable yield loss – $12 per acre control cost = –$2.40 per acre, a loss if the field is treated). However, if the percentage infestation were 60 percent, control would be economically justified ($14.40 per acre preventable yield loss – $12 per acre control cost = $2.40 per acre, a gain). Typically, if expected yield, price per bushel of corn, or anticipated percentage control increases, economic justification for control is more likely. Conversely, if expected yield or price per bushel of corn decreases, or if cost of control increases, economic justification for control is less likely.

Much of the information and suggested guidelines on the worksheets were derived from research trials conducted over many years in numerous locations throughout the Corn Belt. However, if your experience or environmental conditions in your area suggest that other figures might be more accurate, use them instead. For example, if you believe you can achieve 90 percent control with a certain insecticide, use 90 percent instead of 80 percent (our average guideline). If you estimate that survival is less or more than 20 percent (for whatever reason), multiply the percentage survival (decimal point) by 23 (average number of eggs in a mass) to obtain an estimated average number of borers per plant.

For the most effective corn borer control, apply treatments soon after egg hatch to kill the young larvae before they bore into the plant. The larvae begin tunneling into stalks about 10 days after hatching.

Managing corn borers with tillage. Fall plowing and shredding stalks significantly reduce the number of corn borers that overwinter within a given field.

However, there will be little effect on the likelihood of borer injury the following year if nearby fields are not shredded or plowed. Moths that emerge from fields not shredded or plowed may fly to nearby fields to lay eggs, especially if the nearby fields were planted earlier. As a consequence, fall plowing or stalk shredding will not guarantee a reduction in problems in individual fields.

Insect Pests of Soybeans

Although many insects and mites feed on soybeans, annual problems with insects and mites are infrequent in Illinois. Only a few reach outbreak proportions in Illinois, usually in conjunction with extreme weather patterns. Twospotted spider mites caused serious yield reductions during the drought of 1988, for example.

Some of the most common insect pests are defoliators, including bean leaf beetles, blister beetles, grasshoppers, green cloverworms, Japanese beetles, thistle caterpillars, webworms, and woollybear caterpillars. General economic thresholds have been established for these pests. Soybeans can tolerate considerable defoliation without yield reduction, although tolerance to defoliation depends upon the stage of plant growth and stress to the plant. While the plants are growing and producing new leaves, and again after the seeds are completely filled, soybeans can withstand considerable leaf-feeding injury. Defoliation must exceed 30 to 40 percent before yield is affected. Soybean plants are more susceptible to yield-reducing injury during the blooming and pod-filling stages, so the economic threshold during these stages is 20 percent defoliation.

A few pests of soybeans suck fluids from the plants: potato leafhoppers, spider mites, and thrips. Of these, only spider mites are capable of being a serious threat. Some insects, like cutworms, grape colaspis, and seedcorn maggots, attack the underground parts of soybean plants. Pod feeders include bean leaf beetles, corn earworms, grasshoppers, and stink bugs.

Bean leaf beetle

Description. Bean leaf beetles are about ¼ inch long, with considerable variation in color pattern. The background color may be yellow, green, tan, or red. Most beetles' wing covers have four black spots and black stripes along the edges, although these markings may be absent. A black triangle is always present at the base of the wing covers just behind the prothorax, the "neck" area between the head and wing covers.

Life cycle and damage. The beetles overwinter under debris in protected areas. When temperatures warm in the spring, the beetles fly into alfalfa and clover fields to feed but do not lay eggs there. As soon as soybeans begin emerging, the beetles abandon alfalfa and clover fields to colonize soybean fields. They feed on the cotyledons, leaves, and stems of emerging soybeans and lay eggs in the soil. The eggs hatch in a few days, and the larvae feed on the roots and nodules of the plants. The larvae are white, with dark-brown areas at both ends. When the larvae finish feeding, they pupate.

Adults of the first generation begin to emerge in July, but the peak occurs in late July or early August. The beetles feed on the soybean foliage, leaving small holes in the leaves. If the infestation is severe, soybean plants may be completely riddled with holes.

The beetles again lay eggs in soybean fields, and a second generation occurs. Adults of the second generation begin emerging in September. They do not lay eggs, but they remain in the soybeans as long as there are tender plant parts on which to chew. They may chew on pods after the leaves become old, and their feeding creates scars that provide an avenue for entry of spores of various fungal diseases that normally are blocked by the pericarp. Mild infection results in seed staining; severe infection results in seed contamination. As the temperatures decrease, the beetles seek overwintering sites in wooded areas.

Management suggestions. Monitoring for bean leaf beetles should begin when soybean seedlings emerge and resume when first-generation adults are feeding on the leaves in July and August. The pod-filling stage is considered the most critical stage of growth. Economic damage does not occur until beetle density exceeds 16 per foot of row early in the seedling stage of development and 39 per foot of row at stage V-2+. Consequently, an insecticide application for control of bean leaf beetles attacking seedling soybeans probably is rarely justified. However, an insecticide spray may be economically justified during the pod-filling stage if defoliation exceeds 20 percent.

Recent research from the University of Nebraska indicates that economic thresholds for bean leaf beetles for R5–R6 soybeans in 30-inch rows range from 3.97 to 6.05 per foot of row, depending on the value of the soybeans and cost of control. Economic thresholds for bean leaf beetles for R5–R6 soybeans in 7-inch rows range from 0.93 to 1.41 per foot of row. As the value of soybeans decreases and the cost of control increases, the economic threshold increases. As the value of soybeans increases and the cost of control decreases, the economic threshold decreases.

The economic threshold for beetles that are damaging pods is 10 or more beetles per foot of row and 5 to 10 percent injured pods.

Management Worksheet for
First-Generation Corn Borer

_________ % of 100 plants infested x _________ average no. borers/infested plant = _________ borers/plant
(use a decimal)

_________ borers/plant x _________% yield loss/borer* = _________ % yield loss
(do not use a decimal)

_________ % yield loss x _________ expected yield (bu/acre) = _________ bu/acre loss
(use a decimal)

_________ bu/acre loss x $_________ price/bu = $ _________ loss/acre

$_________ loss/acre x _________ % control = $ _________ preventable loss/acre
(80% for granules) (use a decimal)
(50% for sprays)

$_________ preventable loss/acre – $ _________ cost of control/acre =

$ _________ gain (+) or loss (–) per acre if treatment is applied

* 5% for corn in the early whorl stage; 4% (late whorl); 6% (pretassel).

SAMPLE

Management Worksheet for
First-Generation Corn Borer

40 % of 100 plants infested x 1.5 average no. borers/infested plant = 0.6 borers/plant
(use a decimal)

0.6 borers/plant x 5 % yield loss/borer* = 3.0 % yield loss
(do not use a decimal)

3.0 % yield loss x 160 expected yield (bu/acre) = 4.8 bu/acre loss
(use a decimal)

4.8 bu/acre loss x $2.50 price/bu = $ 12.00 loss/acre

$12.00 loss/acre x 80 % control = $ 9.60 preventable loss/acre
(80% for granules) (use a decimal)
(50% for sprays)

$9.60 preventable loss/acre – $ 12.00 cost of control/acre =

– $ 2.40 gain (+) or loss (–) per acre if treatment is applied

* 5% for corn in the early whorl stage; 4% (late whorl); 6% (pretassel).

Management Worksheet for Second-Generation Corn Borer

_________ number of egg masses/plant x 4 borers/egg mass* = _________ borers/plant
(cumulative counts, taken a few days apart)

_________ borers/plant x _________ 3% yield loss/borer** = _________ % yield loss
(do not use a decimal)

_________ % yield loss x _________ expected yield = _________ bu/acre loss
(use a decimal)

_________ bu/acre loss x $_________ price/bu $ _________ loss/acre

$_________ loss/acre x ___75___ % control = $ _________ preventable loss/acre
(use a decimal)

$_________ preventable loss/acre – $ _________ cost of control/acre =

$ _________ gain (+) or loss (–) per acre if treatment is applied

* Assumes survival rate of 20 percent (4 borers/egg mass).
** 5% for corn in the early whorl stage; 4% (late whorl); 6% (pretassel); 4% (pollen shedding); 3% (kernels initiated). Use 3% per borer per plant if infestation occurs after silks are brown. The potential economic benefits of treatment decline rapidly if infestations occur after corn reaches the blister stage.

Other pod feeders
In addition to bean leaf beetles, corn earworms, grasshoppers, and stink bugs may injure soybean pods in Illinois; however, the occurrence of corn earworms in soybeans in Illinois is infrequent.

Grasshoppers. Grasshoppers cause more direct injury to the soybean seeds. Because they have strong chewing mouthparts, grasshoppers often chew through the pod wall and take bites out of or devour entire seeds. If more than 5 to 10 percent of the pods are injured by grasshoppers, an insecticide application may be warranted.

Stink bugs. Green stink bugs overwinter as inactive adults in wooded areas or under leaf litter. During the early months of summer, the adults feed on berries in trees, especially dogwoods. Stink bugs are first found in soybean fields during August. They undergo incomplete metamorphosis (immature bugs resemble the adults), which requires approximately 45 days from egg hatch to adult emergence. There is usually only one generation of green stink bugs per year in Illinois.

Immature stink bugs (nymphs) have a flashy display of black, green, and yellow or red colors and short, stubby, nonfunctional wing pads. The adults are large (about ⅝ inch long), light-green, shield-shaped bugs with fully developed wings. Both adults and nymphs have piercing and sucking mouthparts for removing plant fluids.

Stink bugs feed directly on pods and seeds; however, their injury is difficult to assess because their piercing, sucking mouthparts leave no obvious feeding scars. Stink bugs use their mouthparts to penetrate pods and puncture the developing seeds. They inject digestive enzymes into seeds, and the feeding wound provides an avenue for diseases to gain entry into the pod. Seed quality also is reduced by stink bug feeding, and beans are more likely to deteriorate in storage. An insecticide application for control of stink bugs may be warranted when the level of infestation reaches one adult bug or large nymph per foot of row during pod fill.

Other species of stink bugs also occur in soybeans. The brown stink bug has feeding habits and biology similar to those of the green stink bug. The brown stink bug should not be confused with the beneficial spined soldier bug. These two species can be distinguished from each other by examining the

feeding beak and underside of the abdomen. The beak of the brown stink bug is slender and embedded between the lateral parts of the head. The base of the beak of the spined soldier bug is stout and free from the lateral parts. In addition, the spined soldier bug has a dark round spot located centrally on the underside of its abdomen (belly). Be aware of the species present in a soybean field before making a control decision.

Spider mites

Description. The most common mite species found in soybean fields in Illinois is the twospotted spider mite. These tiny mites (0.002 inch), related to spiders, have four pairs of legs in the adult stage and range in color from pale yellow to brown.

Life cycle and damage. Spider mites hatch from very small eggs. Larvae with six legs emerge from the eggs and progress through two nymphal stages, each with eight legs. After the last nymphal molt, the eight-legged adults emerge. Spider mites complete a generation in 1 to 3 weeks, depending on environmental conditions (primarily temperature).

Spider mites may be blown into soybean fields or carried in by equipment or animals. They also crawl from weed hosts to soybean plants, so infestations usually appear first along field edges or in spots within a field. Mites can move throughout fields by "ballooning," that is, by spinning webs and moving to a position on a leaf from which they can be blown aloft. They can also move from row to row by bridging (moving across leaves in contact) when the canopy is nearly closed.

Spider mites have piercing, sucking mouthparts with which they puncture plant cells and remove plant juices. Damaged plant cells do not recover. Initial injury results in a yellow speckling of the leaves. Heavy infestations cause leaves to wilt and die. Another sign of the presence of spider mites is the webbing they produce on the undersides of the leaves.

Outbreaks of spider mites are associated with hot, dry weather; populations usually peak by mid- to late season. If the soybeans have an adequate supply of moisture, the mites usually do not cause any economic damage.

Management suggestions. A miticide for control of spider mites might be warranted when 20 to 25 percent discoloration is noted before pod set or when 10 to 15 percent discoloration is noted after pod set. Watch field margins closely for symptoms of mite injury as early as late June, but especially during late July and August. Confining the miticide application to border rows and other areas of confirmed infestation is recommended.

Insect Pests of Wheat

In Illinois, few insects cause economic damage to wheat. However, when outbreaks of insects coincide with the head-filling stage of wheat growth, yield losses can be serious. Most of the potential pests are defoliators, such as armyworms and cereal leaf beetles, that may cause extensive injury to the flag leaves. Other pests include Hessian flies and several species of aphids.

Armyworm

The armyworm feeds on several field and forage crops. Armyworms prefer grasses and grain crops such as wheat and corn but occasionally can be found in forage legume crops.

Description. Newly hatched larvae are pale green with longitudinal stripes and a yellow-brown head. Fully grown larvae are about 1½ inches long and green-brown, with two orange stripes on each side. Several longitudinal stripes mark the remainder of the body. Each proleg (the false, peglike legs on the abdomen of a caterpillar) has a dark band. The moth is tan or gray-brown and has a 1½ -inch wingspan. A small white dot in the center of each forewing is a distinguishing mark.

Life cycle and damage. Few armyworms overwinter in Illinois, but some partly grown larvae probably survive the winter under debris in southern counties. Pupation occurs in April; the moths emerge and begin laying eggs in May. Moths that migrate from southern states into Illinois add to the resident population.

Moths prefer to lay eggs on grasses or grains. The eggs hatch in about a week, and the larvae begin to feed on foliage. Young larvae scrape the leaf tissues; older larvae feed from the edges of the leaves and consume all of the tissue. Larvae feed only at night or on cloudy days. After feeding, the larvae pupate under debris or in the soil, and the moths emerge to begin another cycle. There are two or three generations each year in Illinois.

Armyworm moths may lay numerous eggs in wheat fields, and the larvae feed until the grain matures or the wheat is harvested. The larvae feed on the leaves, working their way up from the bottom of the plants. Injury to the lower leaves causes no economic loss, but injury to the upper leaves, especially the flag leaf, can result in yield reduction. After armyworms devour the flag leaves, they often chew into the tender stem just below the head, causing the head to fall off. After the grain matures or is harvested, the larvae will migrate into adjacent cornfields. Large numbers of larvae can destroy corn plants within a day or two.

Management suggestions. Early detection of an armyworm infestation is essential for effective management. Examine dense stands of wheat for larvae. If the number exceeds 6 nonparasitized worms ¾ to 1¼ inches long per foot of row, an insecticide may be justified.

Weather and natural enemies are the major causes of reductions in armyworm numbers. Hot, dry weather promotes the development of parasitoids and diseases, reducing populations of armyworms. Cool, wet weather is most favorable for an outbreak.

Cereal leaf beetle

Cereal leaf beetles annually cause some injury to wheat in southern and central Illinois. Mild winters and lush fall growth create excellent overwintering conditions for the beetles.

Description. The cereal leaf beetle adult is hard-shelled and about 3/16 inch long. Its wing covers and head are metallic blue-black; its legs and the front segment of its thorax (just behind the head) are red-orange. The larva is slightly longer than the adult and resembles a slug. Its skin is yellow to yellow-brown, but the larva carries a moist glob of fecal material on its back that makes it look black.

Life cycle and damage. Adults overwinter in clusters in sheltered areas. In the spring, the beetles fly to fields of winter wheat and other small grains. When spring oats emerge, the beetles quickly infest the young plants. They feed for about 2 weeks before they lay eggs. Eggs usually hatch in 5 days, and the larvae grow and feed for about 10 days. After they finish feeding, the larvae descend to the ground and pupate in the soil. New beetles emerge after 2 to 3 weeks. These beetles often fly to the edges of cornfields and feed on the leaves. After feeding for about 2 weeks, the beetles enter summer hibernation.

The larvae eat only the surface of wheat leaves, so injured plants are silvery in appearance. Severely damaged fields appear frosted. Yield losses occur when the larvae feed on the flag leaves.

Management suggestions. Control may be warranted when the combination of eggs and larvae average 3 or more per stem or there is an average of 1 or more large larvae per stem.

Adults eat longitudinal slits between the veins; they eat completely through the leaves of both wheat and corn. Corn plants usually recover from this injury.

Hessian fly

Although Hessian flies have not caused economic damage to wheat in Illinois for many years, their continuing presence and development of new biotypes pose a constant threat to wheat growers. In fact, many growers have become complacent about managing Hessian flies because resistant varieties have kept them under control for several years. However, the recent development of a new biotype indicates that management of Hessian flies is still important.

Description. The damaging stage is the larva, or maggot, which is reddish when it first emerges from the egg, and then turns glistening white. A Hessian fly maggot (1/16 inch long) has no head or legs, and its body is tapered toward the front end, which contains mouth hooks for feeding. A Hessian fly adult resembles a very small (⅛ inch) mosquito and is sooty black with one pair of wings. The small (⅛ inch), elongated, brown puparium, commonly called a "flaxseed," can be found behind leaves next to the stem.

Life cycle and damage. The Hessian fly overwinters as a full-grown maggot inside a puparium. In the spring, maggots change into pupae inside the puparia and emerge as adults. After females have mated, they lay eggs in the grooves on the upper sides of wheat leaves. After hatching from eggs, the maggots move behind the leaf sheaths and begin feeding on the stem. The maggots feed for about 2 weeks and then form a puparium in which they pupate, usually well before harvest time. They remain in this stage in the stubble throughout the summer. Flies emerge again in late summer and seek egg-laying sites on volunteer wheat plants or on fall-seeded wheat. After the eggs hatch, the fall generation of maggots begins feeding on the seedling plants.

Wheat infested in the fall usually is stunted, and the leaves are dark blue-green, thickened, and more erect than healthy leaves. Severely damaged plants may die during the winter. In the spring, injured plants appear much like they do in the fall. In addition, infested plants often break over when the heads begin to fill.

Management suggestions. Because chemical controls are neither a practical nor a reliable solution to Hessian fly problems in wheat, the following tactics are recommended to manage this pest:

- Destroy wheat stubble and volunteer wheat.
- Plant resistant or moderately resistant wheat varieties.
- Plant wheat after the fly-free date (Table 17.03).

Some producers continue to plant winter wheat before established fly-free dates. By not adhering to these dates, growers are placing greater pressure upon the ability of resistant wheat varieties to withstand Hessian fly infestations. Consequently, the potential longevity and usefulness of Hessian fly–resistant wheat varieties will be shortened. The dates

listed in Table 17.03, ranging from September 17 at the Wisconsin border to October 12 at the southern tip of Illinois, are the earliest dates that wheat should be seeded to avoid egg laying by the fall generation of Hessian fly females. Where wheat is seeded on or after the fly-free date for a specific location, Hessian fly adults usually emerge and die before the crop is out of the ground.

Hessian flies in Illinois have developed a new biotype (L) that has overcome the resistance genes in commercially available wheat hybrids. Consequently, planting wheat after fly-free dates is even more critical because reliance upon formerly resistant wheat varieties will not provide adequate control of Hessian flies.

Table 17.03. Average Date of Seeding Wheat for the Highest Yield

County	Average date of seeding wheat for the highest yield	County	Average date of seeding wheat for the highest yield
Adams	Sep. 30–Oct. 1	Lee	Sep. 19–21
Alexander	Oct. 12	Livingston	Sep. 23–25
Bond	Oct. 7–9	Logan	Sep. 28–Oct. 3
Boone	Sep. 17–19	Macon	Oct. 1–3
Brown	Sep. 30–Oct. 2	Macoupin	Oct. 4–7
Bureau	Sep. 21–24	Madison	Oct. 7–9
Calhoun	Oct. 4–8	Marion	Oct. 8–10
Carroll	Sep. 19–21	Marshall-Putnam	Sep. 23–26
Cass	Sep. 30–Oct. 2	Mason	Sep. 29–Oct. 1
Champaign	Sep. 29–Oct. 2	Massac	Oct. 11–12
Christian	Oct. 2–4	McDonough	Sep. 29–Oct. 1
Clark	Oct. 4–6	McHenry	Sep. 17–20
Clay	Oct. 7–10	McLean	Sep. 27–Oct. 1
Clinton	Oct. 8–10	Menard	Sep. 30–Oct. 2
Coles	Oct. 3–5	Mercer	Sep. 22–25
Cook	Sep. 19–22	Monroe	Oct. 9–11
Crawford	Oct. 6–8	Montgomery	Oct. 4–7
Cumberland	Oct. 4–5	Morgan	Oct. 2–4
DeKalb	Sep. 19–21	Moultrie	Oct. 2–4
DeWitt	Sep. 29–Oct. 1	Ogle	Sep. 19–21
Douglas	Oct. 2–3	Peoria	Sep. 23–28
DuPage	Sep. 19–21	Perry	Oct. 10–11
Edgar	Oct. 2–4	Piatt	Sep. 29–Oct. 2
Edwards	Oct. 9–10	Pike	Oct. 2–4
Effingham	Oct. 5–8	Pope	Oct. 11–12
Fayette	Oct. 4–8	Pulaski	Oct. 11–12
Ford	Sep. 23–29	Randolph	Oct. 9–11
Franklin	Oct. 10–12	Richland	Oct. 8–10
Fulton	Sep. 27–30	Rock Island	Sep. 20–22
Gallatin	Oct. 11–12	St. Clair	Oct. 9–11
Greene	Oct. 4–7	Saline	Oct. 11–12
Grundy	Sep. 22–24	Sangamon	Oct. 1–5
Hamilton	Oct. 10–11	Schuyler	Sep. 29–Oct. 1
Hancock	Sep. 27–30	Scott	Oct. 2–4
Hardin	Oct. 11–12	Shelby	Oct. 3–5
Henderson	Sep. 23–28	Stark	Sep. 23–25
Henry	Sep. 21–24	Stephenson	Sep. 17–20
Iroquois	Sep. 24–29	Tazewell	Sep. 27–Oct. 1
Jackson	Oct. 11–12	Union	Oct. 11–12

Table 17.03. Average Date of Seeding Wheat for the Highest Yield (cont.)

County	Average date of seeding wheat for the highest yield	County	Average date of seeding wheat for the highest yield
Jasper	Oct. 6–8	Vermilion	Sep. 28–Oct. 2
Jefferson	Oct. 9–11	Wabash	Oct. 9–11
Jersey	Oct. 6–8	Warren	Sep. 23–27
JoDaviess	Sep. 17–20	Washington	Oct. 9–11
Johnson	Oct. 10–12	Wayne	Oct. 9–11
Kane	Sep. 19–21	White	Oct. 9–11
Kankakee	Sep. 22–25	Whiteside	Sep. 20–22
Kendall	Sep. 20–22	Will	Sep. 21–24
Knox	Sep. 23–27	Williamson	Oct. 11–12
Lake	Sep. 17–20	Winnebago	Sep. 17–20
LaSalle	Sep. 19–24	Woodford	Sep. 26–28
Lawrence	Oct. 8–10		

AUTHORS

Kevin L. Steffey
Department of Crop Sciences

Michael E. Gray
Department of Crop Sciences

Chapter 18. Disease Management for Field Crops

Successful management of field crop diseases that are found in Illinois is based on a thorough understanding of factors influencing disease development and expression. Strategies should include measures to reduce losses in the current crop as well as considerations for future plantings.

The interaction of four factors influences the development of all plant diseases: (1) the presence of a susceptible host crop; (2) a pathogen (disease-causing agent) capable of colonizing the host; (3) an environment that favors the pathogen and not the host; and (4) adequate time for economic damage and loss to occur. All plant disease management is directed toward disrupting one or more of these factors.

Among measures used to manage plant diseases are crop rotation, genetic resistance, fungicides, and cultural (agronomic) practices. The success of these measures depends on how carefully crops are scouted and diseases assessed. Regular scouting of crops increases the likelihood that disease management will be properly applied and can reduce the unnecessary use of pesticides. Pesticides are best used only when there is threat of an epidemic deemed uncontrollable through the use of other measures.

Fungicides

Fungicide Application

At present, aircraft are the best vehicles for applying foliar fungicides to agronomic crops. Some aircraft may not be equipped or calibrated to do this job, so it is important to select an aerial applicator who is familiar with disease control and whose aircraft has been properly calibrated for uniform, thorough coverage of all above-ground plant parts. With the equipment now available, a reasonable job of applying fungicides requires a minimum of 5 gallons of water carrier per acre. Superior coverage may be obtained with more water, but the cost may be prohibitive. Conversely, a lower volume (less than 3 to 4 gallons per acre) gives correspondingly poorer control. Five gallons of water can be applied uniformly using about 30 to 70 properly spaced nozzles, depending on the aircraft. The nozzles should be D-8 to D-12, hollow cone, with No. 45 or No. 46 cores. The final decision on nozzle number, size, swath width, and placement depends on the air speed, pressure, and volume desired. Droplet size is also important. Ideally, droplets should measure 200 to 400 microns for thorough and uniform coverage.

Use of Adjuvants

When it is compatible with the product label, the addition of a spray adjuvant (surfactant) to the spray mix is suggested. Adjuvants can help disperse fungicides and improve coverage. They are especially helpful for corn and small grains.

Nematicide Application

Granular nematicides/insecticides registered for use on field crops may be used as in-furrow or band treatments, depending on the product label. In general, band applications have given more consistent control than in-furrow applications. Follow the manufacturer's suggestions on incorporation. Nematicides are not designed to replace crop rotation and the use of resistant crop varieties in a management program. Successful nematode management is based on a combination approach that may include pesticides. However, pesticides alone will not provide adequate control and may produce additional environmental problems.

Fungicide Guidelines

Seed treatments. The greatest benefits of fungicide seed treatments will be found (1) where low seeding rates are used; (2) where seed that is of poor quality because of fungal infection must be used; and (3)

where seed is planted in a seedbed in which delays in germination or emergence are likely.

Fungicide seed treatments are not a substitute for high-quality seed and will not improve the performance of seed that is of low quality due to mechanical damage or physiological factors. Treated seed of low quality will not produce stands or yields equal to those of untreated high-quality seed. Only high-quality seed should be considered for planting.

Disease Management of Specific Crops

Although disease management recommendations vary depending on the host crop, many techniques are applicable to all field crops. For specific disease control recommendations, consult the current edition of the *Illinois Agricultural Pest Management Handbook* and other chapters in this publication.

Integrated Pest Management

Alfalfa Disease Management

Alfalfa is subject to a number of seedling blights, root and crown rots, and leaf blights. Losses can be minimized by an integrated management approach including these steps:

1. Growing winter-hardy, disease-resistant varieties.
2. Planting high-quality, disease-free seed produced in an arid area.
3. Providing a well-drained, well-prepared seedbed.
4. Using crop rotation with nonlegumes.
5. Cutting in a timely manner to minimize losses to foliar blights.
6. Using proper fertilization practices and maintaining proper pH.
7. Avoiding cutting or overgrazing during the last 5 or 6 weeks of the growing season.
8. Controlling insects and weeds.
9. Cutting only when foliage is dry.
10. Destroying unproductive stands.
11. Following other suggested agronomic practices.

Table 18.01 lists the most common diseases in Illinois and the effectiveness of various management methods. No control measures are necessary or practical for several of the common alfalfa diseases, including bacterial blight or leaf spot, bacterial stem blight, downy mildew, and rust. For other diseases, producers should select resistant varieties. Specific recommendations are found in this handbook in Chapter 8, "Hay, Pasture, and Silage."

Planting disease-resistant varieties. Many newer varieties offer resistance to bacterial wilt, Fusarium wilt, Verticillium wilt, common leaf spot, Lepto (pepper) leaf spot, spring black stem, anthracnose, and Phytophthora root rot. However, no variety is resistant to all common diseases. Alfalfa producers should identify the common pathogens in their areas and select varieties according to local adaptability, high-yield potential, and resistance to those common pathogens.

Choosing planting sites and crop rotation. The choice of planting site often determines which diseases are likely to occur because most pathogens survive between growing seasons on or in crop debris, volunteer alfalfa, and alternate host plants. Pythium and Phytophthora seedling blights, for example, are more common in heavy, compacted, or poorly drained soils and survive in infected root tissues. Leaf blighting fungi survive in undecayed leaf and stem tissues. These pathogens die out once residues decay.

Other pathogens are dispersed by wind currents and can be found in almost any field. Alfalfa mosaic viruses are transmitted by aphids that may be blown many miles. Thus, planting site selection alone will not ensure a healthy crop.

Rotating crops. The diseases strongly associated with continuous alfalfa production include bacterial wilt, anthracnose, a variety of fungal crown and root rots, Phytophthora root rot, Fusarium wilt, Verticillium wilt, spring and summer black stem, common and Lepto leaf spots, bacterial leaf spot, and Stagnospora leaf and stem spot. Rotating crops and using tillage to encourage residue decomposition before the next alfalfa crop is planted will help reduce the incidence of many diseases.

Since most alfalfa pathogens do not infect plants in the grass family, rotation of 2 to 4 years with corn, small grains, sorghum, and forage grasses will help reduce disease levels.

Cutting of alfalfa in the mid- to late-bud stage. Cutting heavily diseased stands before bloom and before the leaves fall will maintain the quality of the hay and remove the leaves and stems that are the source of infection (primary inoculum) for later disease. This will help ensure that succeeding cuttings have a better chance of remaining healthy. Cutting in the mid- to late-bud stage, harvesting at 30- to 40-day intervals, and cutting the alfalfa short are practices that help to control most leaf and stem diseases of alfalfa.

Table 18.01. Alfalfa Diseases That Reduce Yields in Illinois and the Relative Effectiveness of Various Control Measures

Disease	Planting winter-hardy, resistant varieties	Using high-quality seed	Having a well-drained soil, pH 6.5 to 7	Employing correct crop rotation	Achieving adequate, balanced fertility	Cutting in mid- to late-bud stage	Avoiding late cutting and planting	Avoiding rank growth and high stubble	Maintaining insect and weed control
Bacterial wilt	1		2	3	3	3			3
Dry root and crown rots, decline	3	3	2	2	2		2	3	2
Phytophthora root rot	1		2	2	3		2		
Fusarium wilt	1		3	2	3		2	3	3
Verticillium wilt	1	2			3		3		
Anthracnose	1		3	1	2			2	3
Spring black stem	1	2	3	1	3	2		2	3
Summer black stem		2	3	2	3	2		2	3
Common or Pseudo-peziza leaf spot	1		3	2	2	2		2	3
Stemphylium or zonate leaf spot	3	2		2	3	2		2	3
Lepto or pepper leaf spot	2		3	2	3	2		2	3
Yellow leaf blotch		2	3	2	2	2		2	3
Stagnospora leaf and stem spot			3	2	3	2		2	3
Rhizoctonia stem blight		2	2		2	2		2	3
Seed rot, seedling blights, damping-off		1	2	3	2				3
Sclerotinia crown and root rot	2	3	2	2	2	3	2	2	2
Mosaics		3							2

1 = Highly effective control measure; 2 = moderately effective; 3 = slightly effective. A blank indicates no effect.

Cutting only when foliage is dry. This practice minimizes the spread of fungi and bacteria that cause leaf and stem diseases, wilts, and crown and root rots.

Controlling insects. Insects commonly provide wounds by which wilt, crown- and root-rotting fungi, and bacteria enter plants. Insects also reduce plant vigor, increasing the risk of stand loss from wilts and root and crown rots.

Controlling weeds. Do not allow a thick growth of weeds to mat around alfalfa plants. Like rank, tall plant growth, weeds also reduce air movement; they slow the drying of the foliage and lead to serious crop losses from leaf and stem diseases. Seedling stands under a thick companion crop, such as oats, are commonly attacked by leaf and stem diseases. Weeds also may harbor viruses that can be transmitted to alfalfa by the feeding of aphids. Keep down broadleaf weeds in fence rows and drainage ditches, along roadsides, and in other waste areas. Such places serve as a source of mosaic viruses. Whenever possible, do not grow alfalfa close to other legumes, especially clovers, garden peas, and beans. Many of the same viruses that infect alfalfa attack these and other legumes.

Soybean Disease Management

Soybean disease management is based upon an integrated system using resistant varieties, crop rotation, tillage (where feasible), fungicides, balanced soil fertility, high-quality seed, scouting, and proper insect and weed control. The use of several of these management practices will help disrupt the combination of factors necessary for disease development. Table 18.02 summarizes the effect of these practices.

Variety selection. All soybean disease management programs should begin with the selection of a variety with resistance to the most common pathogens in the

Table 18.02. Soybean Diseases That Reduce Yields in Illinois and the Relative Effectiveness of Various Control Measures

Disease	Resistant or tolerant varieties	Crop rotation	Clean plow-down	High seed quality	Fungicides	Other controls and comments
Phytophthora root rot	1				3	Numerous races of the fungus are known. Avoid poorly drained areas and soil compaction.
Pythium, Phytophthora, Rhizoctonia, and Fusarium seedling blights and root rots				1	2	Plant high-quality seed in a warm (55 to 60°F), well-prepared seedbed. Shallow planting may help establish uniform, vigorous stands.
Charcoal root rot			2	3		Early planting, deep and clean plowing, balanced fertility, narrow rows, and avoiding moisture stress provides some control. Avoid high seeding rates.
Soybean cyst nematode	1	1	3		3 (nematicides)	Early planting and eliminating susceptible weeds aids in control. Avoid moving contaminated soil from field to field by equipment, water, or other means. Crop rotations of 3 years or more may be necessary even when using resistant varieties. Maintain balanced fertility. Soil analysis should be used in decision making.
Pod and stem blight, anthracnose, stem canker		2	2	1	1	Fungicides are suggested to aid in producing high-quality seed. Grain producers may have higher yields in warm, wet seasons. Plant full-season varieties.
Cercospora leaf blight (purple seed stain), Septoria brown spot, frogeye leaf spot	1	2	2	2	1	These diseases may be more important in narrow-row culture systems.
Bacterial blight, bacterial pustule, wildfire	1	2	2	2		Seed should *not* be saved from fields that are heavily infected with these diseases.

Table 18.02. Soybean Diseases That Reduce Yields in Illinois and the Relative Effectiveness of Various Control Measures (cont.)

Disease	Resistant or tolerant varieties	Crop rotation	Clean plow-down	High seed quality	Fungicide	Other controls and comments
Downy mildew	2	2	2	2		This disease, which primarily affects seed quality, may become more important in narrow-row culture systems.
Sclerotinia white mold	2	3	2		?	The effectiveness of fungicide sprays is unknown at this time. Varietal differences are known, but no resistant soybeans have been released.
Powdery mildew	1					
Soybean mosaic, bean pod mottle, and bud blight viruses				2		Plant seed produced in fields with a low incidence of soybean mosaic. Damage from bud blight may be reduced by bordering soybean fields with 4 to 8 rows or more of corn or sorghum. This may be especially helpful where soybean fields border alfalfa or clover fields. Before planting, apply herbicides to kill broadleaf weeds in fencerows, ditch banks, grass pastures, and the like.
Brown stem rot	1	1				Rotations of 2 to 3 or more years are necessary for control. Soybeans planted as end rows on cornfields aid in carrying over the disease. Early maturing varieties are generally less affected than late-maturing varieties. Resistant varieties act as nonhost crops in rotations.
Sudden death syndrome						See comments for soybean cyst nematode. Early planted or early maturing varieties appear to be more susceptible.

1 = Highly effective control measure; 2 = moderately effective; 3 = slightly effective. A blank indicates no effect.

area. Many high-yielding public and private soybean varieties are available with resistance to important diseases such as Phytophthora root rot, soybean cyst nematode, and brown stem rot. Other, less important diseases can also be controlled with resistant varieties. See Chapter 3 in this handbook for more information on variety selection.

One major concern for soybean producers is the possible appearance of new or unexpected races of a pathogen, particularly for Phytophthora root rot and the soybean cyst nematode. A race is simply a pathogen population with the ability to infect and colonize a normally resistant host plant. Thus, growers lose the expected protection of the resistance genes and essentially have "susceptible" plants. Different races are known to occur in Illinois for both Phytophthora root rot and soybean cyst nematode. If growers experience losses in fields where resistant varieties are planted and other causes can be ruled out, an unusual pathogen race should be suspected.

For Phytophthora root rot, there is the option of selecting resistant or tolerant seed sources. Resistant soybeans contain one or more genes with resistance to specific races of the pathogen. This type of resistance is active from the time of planting until full maturity. It fails only where unusual races occur that are not controlled by the genes in the plant.

Tolerance provides a broad form of resistance to all races of the pathogen. However, it may not provide the level of protection needed where pathogen population levels are extremely high. The major advantage is the protection against all races. However, tolerance is not active in the early seedling stage, and plants are considered susceptible to Phytophthora until one or two true leaves have developed. An application of Apron seed treatment or Ridomil in-furrow is advised to protect tolerant varieties in the early season.

Agronomic characteristics affecting disease development. The relative maturity of soybean cultivars can have a dramatic impact on disease development. Early-maturing varieties are more commonly damaged by pod and stem blight, anthracnose, purple seed stain, and Septoria brown spot. The longer the time from maturity to harvest, the greater the likelihood of damage by these diseases. However, early-maturing varieties are generally less affected by brown stem rot.

Soybean growth habit can also affect disease development. Tall, bushy varieties, for example, are more affected by Sclerotinia white mold than shorter, more compact varieties. However, the shorter varieties may also be more prone to damage by water-splashed pathogens such as Septoria brown spot, pod and stem blight, and purple seed stain. Differences in individual variety resistance may negate the effects of plant height on disease development.

Planting date also affects diseases. Early planted beans typically have a greater incidence of seedling blights if not protected by a fungicide. Conditions in early spring favor these pathogens and may delay the rapid emergence of soybeans. Early planting also increases the incidence of sudden death syndrome when compared to later plantings.

Crop rotation and tillage are very important practices in controlling most diseases of soybeans. Practically all soybean pathogens depend on crop residues for overwintering and do not colonize other hosts. Therefore, when crop residues are removed or are thoroughly decayed and/or when rotation with nonhosts (corn, sorghum, small grains) is used, pathogen population levels decline.

Programs which promote residue decay through tillage or rotations will help reduce such diseases as pod and stem blight, anthracnose, stem canker, powdery and downy mildew, brown stem rot, Sclerotinia white mold, and soybean cyst nematode.

With the increasing acceptance of reduced and no-till practices, the practice of total residue incorporation is declining. Where residues remain on or near the soil surface, it is important to emphasize all other means of control. The presence of residues does not significantly increase disease levels where resistance and crop rotation are practiced.

Row spacing is another factor that can influence disease. Diseases that thrive in cool, wet conditions typically increase where soybeans are planted in narrow rows. If previous soybean crop residue is also present, earlier and more severe epidemics may occur. Diseases such as downy mildew and Sclerotinia white mold are greatly affected by high humidity levels. Narrow rows increase both humidity and disease levels. If tall beans are also planted, there may be little air circulation within the canopy. Where white mold or downy mildew are problems, wider rows or shorter beans will help reduce disease levels.

Wheat Diseases

Wheat disease management is based upon an integrated control program using resistant varieties, high-quality seed, fungicide treatments, proper planting time and site, crop rotation, tillage (where feasible), high fertility, and other cultural practices. Table 18.03 summarizes these measures and the diseases controlled.

Disease-resistant varieties. Growing resistant varieties is the most economical and efficient method of controlling diseases. Resistance to stem rust, leaf rust, loose smut, Septoria diseases, powdery mildew, soilborne wheat mosaic, barley yellow dwarf, wheat streak mosaic, and wheat spindle streak (wheat yellow mosaic) is of major importance in Illinois. No single wheat variety is resistant to all major diseases. Thus, varieties should be selected according to their local adaptability, high-yield potential, and resistance to the most common and serious diseases.

High-quality seed. Seed that has been improperly stored (bin-run) will lose vigor and may develop problems in the seedling stage that continue throughout the season and result in reduced crop yield and quality. Diseases such as bunt, loose smut, basal glume rot, black chaff, ergot, Septoria diseases, Helminthosporium spot blotch or black point, and scab may be carried on, with, or within the seed.

Planting site. The choice of a planting site often determines which diseases are likely to occur because many pathogens survive on or in crop debris, soil, volunteer wheat, and alternate host plants. This is most important in the control of Septoria leaf and glume blotches, Helminthosporium spot blotch, tan or

Table 18.03. Relative Effectiveness of Various Methods of Controlling the Major Wheat Diseases in Illinois

Disease	Resistant varieties	Crop rotation	Clean plow-down	Balanced fertility[a]	Planting after the fly-free date	Fungicides: Seed treatment	Fungicides: Foliar sprays	Other controls and comments
Stem rust	1				3		1	
Leaf rust	1				3		1	
Loose smut	1					1		
Bunt or stinking smut						1		
Septoria leaf blotches	1	2	2		2	3	1	
Septoria glume blotch	1	2	2		3	2	1	
Scab		1	3	3	3	2		Avoid planting adjacent to corn stubble or following corn.
Take-all	2	1	3	2	2			Control virus diseases.
Tan or yellow spot		2	2		3		2	
Cephalosporium stripe		1						
Powdery mildew	1			3	3		1	
Seedling blights			3	3	2		1	
Helminthosporium spot blotch		2			3		2	
Soilborne wheat mosaic virus	1	3			2			
Wheat streak mosaic virus		3	3		2			
Barley yellow dwarf virus	1				1			
Wheat spindle streak virus	1				1			

1 = highly effective control measure; 2 = moderately effective; 3 = slightly effective. A blank indicates no effect.
[a]See Table 18.04 for the effect of the form of nitrogen used.

yellow leaf spot, scab, ergot, take-all, Fusarium and Helminthosporium root rots, crown or foot rots, Cephalosporium stripe, bunt or stinking smut, downy mildew, eyespot or strawbreaker, Pythium and Rhizoctonia root rots, sharp eyespot, soilborne wheat mosaic, and wheat spindle streak mosaic or wheat yellow mosaic. Other diseases are not affected by choice of planting site, including airborne and insect-transmitted diseases. These include barley yellow dwarf virus, wheat streak mosaic virus, and rusts.

Crop rotation. Crop rotation is an extremely important means of reducing carryover levels of many common wheat pathogens. Diseases strongly associated with continuous wheat production include take-all, Helminthosporium spot blotch, tan or yellow spot, crown and foot rots, root rots, head blights, Septoria leaf and glume blotches, black chaff, powdery mildew, Cephalosporium stripe, soilborne wheat mosaic, wheat streak mosaic, scab, downy mildew, eyespot and sharp eyespot, ergot, and anthracnose.

With many common wheat diseases, crop debris provides a site for pathogen populations to survive adverse conditions. Many of these pathogens do not survive once crop debris is decomposed. Rotations of 2 or 3 years with nonhost crops (such as corn, sorghum, alfalfa, and clovers), coupled with other practices that promote rapid decomposition of crop residue, will reduce the carryover populations of these pathogens to very low levels. Soilborne wheat mosaic and wheat spindle streak or wheat yellow mosaic increase when wheat is planted continuously in the same field. To control these diseases, rotations must cover at least 6 years. Using highly resistant varieties is the best way to control losses from these types of diseases.

Replanting the same field to winter wheat following an early summer harvest does not constitute an adequate rotation.

Tillage. Although a clean plow-down is of great help in disease control, the losses to soil erosion should be carefully weighed against potential disease losses. Pathogens dispersed short distances by wind and splashing water may infect crops early and cause more severe losses where debris from the previous wheat crop remains on the soil surface. The need for clean tillage is thus based on the prevalence and severity of diseases in the previous crop, other disease-control practices available, the need for erosion control, rotation plans, and related factors.

If conservation tillage is to be implemented, strict attention must be paid to all other disease-control practices.

Fertility. The effect of fertility on wheat diseases is quite complex. Adequate and balanced levels of nitrogen, phosphorus, potassium, and other nutrients—based on a soil test—will help reduce disease losses, particularly from take-all, seedling blights, powdery mildew, anthracnose, and Helminthosporium spot blotch. Research has shown that the level and form of nitrogen both play an important role in disease severity. The severity of certain diseases is decreased by using ammonia forms of nitrogen (urea and anhydrous ammonia) and is increased by using the nitrate forms of nitrogen. In other cases, the reverse is true. The general effect on disease severity caused by the form of nitrogen used is given in Table 18.04.

Planting time. Planting time can greatly influence the occurrence and development of a number of diseases. Early fall planting and warm soil (before the "fly-free" date) promote the development of certain seed rots and seedling blights, Septoria leaf blotches, leaf rust, powdery mildew, Cephalosporium stripe, Helminthosporium spot blotch, wheat streak mosaic, soilborne wheat mosaic, barley yellow dwarf, and wheat spindle streak mosaic. Wheat that is planted early often has excessive foliar growth in the fall, which favors the buildup and survival of leaf rust, powdery mildew, and the Septoria diseases. Disease buildups in the fall commonly favor earlier and more severe epidemics in the spring. Many of these problems can be avoided if planting is delayed until after the "fly-free" date.

Table 18.04. Effect of the Form of Nitrogen on Various Wheat Diseases

	Nitrogen form	
Disease	Nitrate	Ammonium
Root and crown diseases		
Take-all	Increase	Decrease
Fusarium root rot	Decrease	Increase
Helminthosporium diseases	Decrease	...
Foliar diseases		
Powdery mildew	Increase	...
Leaf and stem rust	Increase	Decrease
Septoria leaf blotch	Increase	...

... = No effect or data not available.

Planting after the "fly-free" date is an effective means of limiting the transmission of viruses and yield losses from virus diseases such as wheat streak mosaic and barley yellow dwarf. The cooler temperatures usually limit the activity of mites and aphids that transmit these viruses. Since fall infections result in the greatest yield losses, serious virus problems can be avoided by late planting. See the nearest Extension office for information on fly-free dates.

Seed treatment. Seed treatment trials in Illinois during the past 17 years have increased yields 3 or more bushels per acre by controlling diseases such as bunt, loose smut, Septoria diseases, seed rots, and seedling blights. Failure to control seedling blights may result in serious winterkill of diseased seedlings.

No single fungicide controls all of the diseases just listed. A combination of fungicides is necessary to obtain broad-spectrum seed protection. Since some seedborne pathogens are more difficult to control than others, the full recommended label rate should always be used.

Foliar fungicides. Septoria leaf and glume blotches, powdery mildew, and rusts may occur every year regardless of the precautions taken. These diseases are favored by rainy, windy weather and heavy dews, and they are a threat whenever such weather prevails from tillering to heading.

Rusts, powdery mildew, and Septoria diseases can be controlled by timely and proper applications of fungicides. The decision to apply fungicides should be based on the prevalence of disease, disease severity, and the yield potential of the crop. As a general guideline, the upper two leaves (flag and flag-1) should be protected against foliar pathogens since head-filling depends largely on the photosynthetic activity of these two leaves. Loss of leaves below flag-1 usually causes little loss in yield.

Weekly scouting for foliar diseases should begin no later than the emergence of the second node (growth stage 6). If diseases are present at this time and weather conditions favor continued disease development (cool and rainy), a fungicide application should be considered. Be certain that diseases are correctly diagnosed to ensure proper fungicide selection. With protectant fungicides the first application should be at early boot stage followed by a second spray 10 to 14 days later, depending on the weather. Systemic fungicides can be applied when diseases become evident on the upper leaves and provide protection for about 18 days. A protectant fungicide may be needed at heading time for late-season disease control.

Corn Disease Management

To prevent losses from disease, it is necessary to follow a comprehensive, integrated program of corn disease management. Such a program should include the use of disease-resistant hybrids, crop rotations, various tillage practices, balanced fertility, fungicides, insect and weed control, and other cultural practices. These practices should relate to the risk potential of the various diseases and the life cycles of disease-causing organisms (pathogens).

Table 18.05 lists those diseases known to cause yield losses in Illinois and the relative effectiveness of various control measures.

Disease-resistant hybrids. The use of resistant hybrids is the most economical and efficient method of disease control. Although no single hybrid is resistant to all diseases, hybrids with combined resistance to several major diseases are available. Corn producers should select high-yielding hybrids with resistance or tolerance to major diseases in their area.

Crop rotation. Many common pathogens require the presence of a living host crop for growth and reproduction. Examples of such corn pathogens include the leaf diseases ("Helminthosporium" leaf diseases, Physoderma brown spot, Goss's bacterial wilt, gray leaf spot, yellow leaf blight, eyespot) and nematodes. Rotating to nonhost crops (e.g., soybeans, alfalfa, clovers, and canola) "starves out" these pathogens, resulting in a reduction in inoculum levels and the severity of disease. Continuous corn, especially in combination with conservation tillage practices, which promote large amounts of surface residue, may result in severe outbreaks of disease. In such cases it is highly advisable to utilize *all* other disease-control measures.

Tillage. Tillage programs that encourage rapid residue decomposition, before the next corn crop is planted, help reduce populations of pathogens that overwinter in or on crop debris. Although a clean plow-down is an important disease-control practice, the possibility of soil loss from erosion must be considered. Other measures can provide effective disease control if conservation tillage is implemented. Examples of diseases partially controlled by tillage include stalk and root rots, "Helminthosporium" leaf diseases, Physoderma brown spot, Goss's bacterial wilt, gray leaf spot, anthracnose, ear and kernel rots, yellow leaf blight, eyespot, and nematodes.

Balanced fertility. Adequate balanced fertility plays an important role in checking the development of such diseases as Stewart's bacterial wilt, seedling blights, leaf blights, smut, stalk rots, ear rots, and nematodes. Diseases are often most severe where there is excess nitrogen and a lack of potassium, or both. Healthy, vigorous plants are more tolerant of diseases and better able to produce a near-normal yield.

Foliar fungicides. One or more "Helminthosporium" leaf blights and rust diseases may occur every year regardless of the precautions taken. If extended periods of moist, overcast weather occur before or shortly after tasseling, these diseases may cause losses of 10 to 30 percent. If significant disease occurs earlier than 2 weeks after tasseling, the application of foliar fungicides may be justified, especially in seed production fields. The decision to apply fungicides should be based on the prevalence and severity of leaf diseases. Leaf blights generally are first seen on the lower leaves. Rusts first appear on the upper leaves.

In general, fungicide applications are economically feasible only in seed-production fields or other specialty corn crops. Weekly scouting for "Helminthosporium" leaf blights and rusts should begin at least 2 weeks before tasseling. If diseases are present and weather conditions favor continued disease development (rainy and overcast), fungicide applications should be considered. Add a label-recommended spreader-sticker (surfactant) to the spray tank to ensure more uniform coverage.

Table 18.05. Corn Diseases That Reduce Yields in Illinois and the Relative Effectiveness of Various Control Measures

Disease	Resistant or tolerant hybrids	Crop rotation	Clean plow-down	Balanced fertility	Fungicides	Other controls and comments
Stewart's bacterial wilt	1			3		Early control of corn flea beetles may be helpful on susceptible hybrids.
Seed rots and seedling blight	2			3	1	Sow injury-free, plump seed. Plant seed in soils 50° to 55°F or above. Prepare seedbed properly and place fertilizer, herbicides, and insecticides correctly.
"Helminthosporium" leaf blights; Northern leaf blight, Northern leaf spot, Helminthosporium leaf spot, Southern leaf blight	1	2	2	3	2	Fungicide applications are generally justified only in seed production fields and only if the lower three leaves up to 2 weeks after tasseling are infected.
Physoderma brown spot		1	3	2		
Yellow leaf blight and eyespot	1	2	1		3	See comments for "Helminthosporium" leaf blights.
Gray leaf spot	2	2	2		3	See comments for "Helminthosporium" leaf blights.
Anthracnose	1	2	1	3		
Crazy top and sorghum downy mildew		1	3	3		Avoid low wet areas, and plant *only* downy mildew-resistant sorghums in sorghum-corn rotations. Control of shattercane (an alternate host) is very important.
Goss's bacterial wilt	1	1	2			Rotations of 2 or more years provide excellent control.
Smut	2	3	3	3		Avoid mechanical injuries to plants. Control insects.
Common and southern rusts		1				Fungicides may be justified in seed-production fields.

1 = Highly effective control measure; 2 = moderately effective; 3 = slightly effective. A blank indicates no effect.
[a]Not affected by crop rotation or tillage.

Table 18.05. Corn Diseases That Reduce Yields in Illinois and the Relative Effectiveness of Various Control Measures (cont.)

Disease	Resistant or tolerant hybrids	Crop rotation	Clean plow-down	Balanced fertility	Fungicides	Other controls and comments
Stalk rots: Diplodia Charcoal Gibberella Fusarium Anthracnose Nigrospora	2	2	2	2		Plant adapted, full-season hybrids at recommended populations and fertility. Control insects and leaf diseases. Survey at 30 to 40 percent moisture to determine potential losses.
Ear and kernel rots: Diplodia Fusarium Gibberella Physalospora Penicillium[a] Aspergillus[a] Others	2	2	3	3		Control stalk rots and leaf blights. Hybrids that mature in a downward position with well-covered ears usually have the least ear rot. Ear and kernel rots are increased by bird, insect, and severe drought damage.
Storage molds: Penicillium Aspergillus, etc.						Store undamaged corn for short periods at 15 to 15.5 percent moisture. Dry damaged corn to 13 to 13.5 percent moisture prior to storage. Low-temperature-dried corn has fewer stress cracks and storage mold problems if an appropriate storage fungicide is used. See a local Extension office for details. Corn stored for 90 days or more should be dried to 13 to 13.5 percent moisture. Inspect weekly for heating, crusting, and other signs of storage molds.
Maize dwarf mosaic	1					Control Johnsongrass and other perennial grasses (alternative hosts) in and around fields.
Wheat streak mosaic	1					Plant winter wheat (an alternative virus host) after the fly-free date and control volunteer wheat. Separate corn and wheat fields. See Report on Plant Diseases No. 123.
Nematodes: Lesion Needle Dagger Sting Stubby-root		2	2	3		Clean plow-down helps reduce winter survival of nematodes. Nematicides may be justified in some situations. See your Extension adviser for information on chemical control.

1 = Highly effective control measure; 2 = moderately effective; 3 = slightly effective. A blank indicates no effect.
A blank indicates no effect.

NOTE: Descriptions of diseases of field crops can be found in the following publications:

- Various Compendia of Plant Diseases (corn, soybeans, and alfalfa), published by the American Phytopathological Society, 3340 Pilot Knob Road, St. Paul, MN 55121.
- Reports on Plant Diseases, published by Plant Pathology Extension, Department of Crop Sciences, University of Illinois. These bulletins provide in-depth information for farmers, consultants, and others needing information about specific plant diseases and their management.

Author

H. Walker Kirby
Department of Crop Sciences

Chapter 19. On-Farm Research

Many farmers have become actively involved in one or more on-farm research projects. These farmers have become involved with such research and the production of new knowledge for several reasons, including (1) the increasing complexity of crop production practices; (2) the declining support for applied research conducted by universities; and (3) the proliferation of products and practices whose benefits are difficult to demonstrate. Such on-farm research projects have included hybrid or variety strip trials conducted in cooperation with seed companies, tillage comparisons, evaluations of nontraditional additives or other products, and nutrient rate studies, as well as other management practice comparisons.

Setting Goals for On-Farm Research

The stated purpose of most on-farm research is "to prove whether a given product or practice works [normally meaning that it returns more than its cost] on my farm." While this may seem an obvious goal, the person conducting or considering conducting on-farm research should understand several implications of such a goal:

1. Like it or not, Illinois farmers operate in a variable environment, with large changes in weather patterns from year to year and with differences in soils within and among fields. These factors may in practice force the operator to modify the on-farm research goal from "proving whether something works" to "finding out under what conditions something works or does not work" or "finding out how often something works." Both of these modifications require that particular trials be run over a number of years and in a number of fields. The key objective of any applied research project—on-farm or not—is to be able to *predict* what will happen when we use a practice or product in the future. The variable conditions under which crops are produced make such predictions difficult.
2. All fields are variable, meaning that a measurement of anything (such as yield) in a small part of a field (a plot) does not perfectly represent that field, much less the whole farm. Such variability can be assessed using the science of statistics: for example, the statistician might look at the yields of six strips of Hybrid A harvested separately and state, "The average yield of Hybrid A in these strips was 155 bushels per acre. But due to the variability among the harvested strips, we can only say that we are 95 percent certain that the actual yield of Hybrid A in this field was between 150 and 160 bushels per acre." In other words, variability means that it is not possible to be completely precise in measuring the effects of a particular treatment. Replicating (treating more than one strip with the same treatment) more times can help narrow the range of unpredictability, but the range will never be zero. Some uncertainty will always be present.

If a whole field is harvested using an accurate yield monitor, the exact yield (for that year) is known, and we also know the range in yields. With on-farm research, it is necessary to apply treatments to only parts of the field since no comparisons are possible if the whole field is treated the same. Suppose the farmer stripped the whole field, with Hybrid A in one side of the planter and Hybrid B in the other side. After the strips of each hybrid were harvested separately, the statistician might be able to state, "Based on the strips chosen to represent Hybrid B, this hybrid yielded 140 bushels per acre, and it is 95 percent certain that the yield of Hybrid B was between 135 and 145 bushels per acre." In this case, since the "confidence intervals" (150 to 160 for Hybrid A; 135 to 145 for Hybrid B) of the two hybrids do not overlap, it is possible to state that the yields of the two hybrids were *significantly different*. But in this realis-

tic example, note that the yields of the two hybrids differed by 15 bushels per acre, and still the confidence intervals came within 5 bushels of overlapping. Now with yield monitors, we can measure yields of the two hybrids, and we can produce a "difference map," which tells us which hybrid yielded more in different parts of the field.

3. Because of the uncertainty, it is necessary to accept that, when measuring yield (or anything else) in applied field research, it is virtually impossible to ever "prove" that some practices or products work or do not work. Even with the most precise trials done in the most uniform fields, it takes a yield difference of at least 2 or 3 bushels per acre (1 to 2 percent) between treatments to allow the researcher to state with confidence that the treatments produced different yields. As a rather silly example, suppose a farmer went out into a corn field, divided the field into twenty 12-row strips, then carefully cut one plant out of every 500 plants in 10 of the strips but did nothing to the other 10 strips. It would be absolutely certain that the farmer's treatment (cutting out 0.2 percent of the plants) affected the yield of the treated strips, but it would also be certain that the farmer would not be able to measure a *significant* yield difference between the two treatments, unless perhaps by accident. The variability between strips in a case like this would simply overwhelm a very small but real treatment effect (the physical removal of the plants by the farmer). Similarly, a crop additive or other practice may give small yield increases or decreases, yet never be *proven* to work or not to work.

Types of On-Farm Trials

A number of different categories of research have been popular as on-farm projects, each with its own challenges. These are discussed below.

Fertilizer Rate Trials

Fertilizer is an expensive input, so rate trials designed to determine a "best" rate, or the effect of reducing rates, have been common. Fertilizer rate is what is called a "continuous" variable—two rates for comparison could differ by 50 pounds per acre, 5 pounds per acre, or 1 pound per acre; the researcher chooses the rates. Whether or not different rates will produce significantly different yields depends, of course, on what rates are selected. This makes the typical "rate reduction" trial difficult to interpret: 140 pounds of nitrogen per acre might or might not produce a different yield from the "normal" 160 pounds of nitrogen per acre, but as was just discussed, a field experiment often will not pick up a small difference. As a result, many rate reduction studies are "successful" in that lower rates do not produce significantly lower yields. But the response to fertilizer rate needs to be generated by using a number of rates—more than just two. And the results should be used to produce a curve showing the response to fertilizer, rather than comparing the yields produced by the various rates. Remember that the researcher or operator chooses the fertilizer rates, and the chance of just stumbling on the "best possible" rate is low.

To illustrate, consider the following corn yields produced in a nitrogen fertilizer rate trial:

Nitrogen rate	Yield (bu/A)
0	100
60	142
120	164
180	163
240	140

Many people looking at these numbers would conclude that 120 pounds of nitrogen must have been the "best" rate, since it gave the highest yield. Figure 19.01 is another way to look at the same data. The curve, generated by a computer, fits the data quite well in this case.

When the data are presented this way, it is easy to see that the "best" rate was not in fact 120 pounds of nitrogen per acre; the rate that would have given the highest yield was actually 148 pounds per acre. It was only by chance that the researcher did not use that

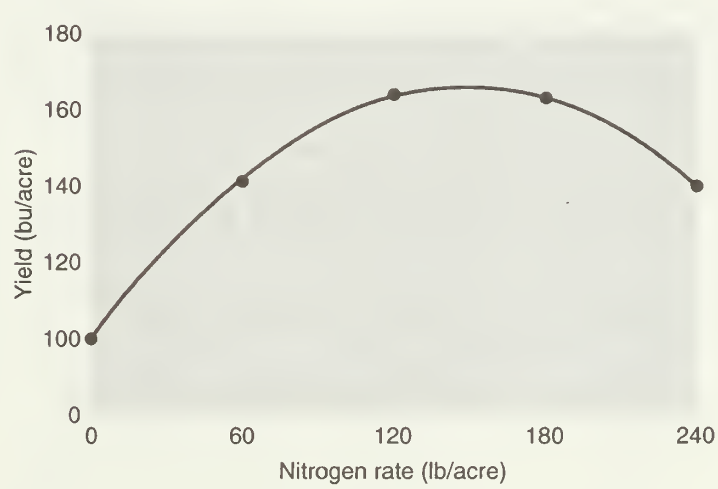


Figure 19.01. A curve fitted to yields from a nitrogen rate trial on corn.

(best) rate, but with only one best rate (one highest point on the curve), the chance of actually using that best rate is low. Because nitrogen fertilizer has a cost, the best economic rate—the rate producing the highest income—is less than the rate that gives the top yield. How much less depends on the prices of nitrogen and corn. In this example, if corn is $3 per bushel and nitrogen costs 20 cents per pound, then the nitrogen rate providing the best return would be about 137 pounds of nitrogen per acre. With lower corn prices or higher N costs, the optimum N rate decreases.

A curve to present data is used for a fertilizer example here, but the same principle applies for any input for which rates are chosen. Examples of such factors include plant population, seed rate, and row spacing.

Hybrid or Variety Comparisons

Hybrid or variety comparisons are very common and are usually done in cooperation with a seed company. Comparisons have very good demonstration value, and when results are combined over a number of similar trials, they can provide reasonable predictions of future performance. Most of these trials are done as single (unreplicated) strips in a field. The results of a single trial do not predict future performance very well. For example, a hybrid that happens to fall in a wet spot in the field may yield poorly only because of its location, not its genetic potential. Seed companies are increasingly averaging the results of multiple strip trials, thereby providing better predictions and making the trials more useful. A farmer who participates in such trials should be sure to ask the company for results from other locations as well.

Many people who work with hybrid or variety strip trials are convinced that the effects of variability can be removed by using "check" strips of a common hybrid or variety planted at regular intervals among the varieties being tested. The yields of such check strips are often used to adjust the yields of nearby hybrids or varieties, on the assumption that the check will measure the relative quality of each area in the field, thus justifying inflation of yields in low-yielding parts of the field and deflation of yields in high-yielding parts. If all variation in a field occurred smoothly and gradually across the field, such adjustments would probably be reasonable. But variation does not occur that way, so it is often unfair to adjust yields of entries simply because the nearby check yielded differently than the average of all of the checks. The use of such checks can provide some measure of variability in the field, but it also takes additional time and space to plant the trial when checks are used. The only way to know for certain whether performance of a variety or hybrid in a strip trial was "typical" is to look at data from a number of trials to see whether performance was consistent.

Tillage

Tillage trials are difficult and often frustrating, in large part because tillage is really not a well-defined term. One farmer's "reduced tillage," for example, may be very different from another farmer's. The same is true for "conventional tillage" and even for "no-tillage" due to the large number of attachments and other equipment innovations. Motivations may also differ substantially: while no-tillage versus conventional tillage may seem like a straightforward comparison, an attitude of "I know I can make no-till work" might produce a very different research outcome from an attitude of "I really don't think no-till yields are as good as in conventional tillage, and I can prove it." This may be an extreme example, but there are indications that tillage trials often are not conducted in a strictly "neutral" research environment.

It is possible to make on-farm comparisons of tillage practices. Treatments for comparison have to be selected carefully, keeping in mind that "if you already know what the results will be, there's very little reason to do research." Because soil type usually affects tillage responses, it is always useful to do tillage trials in several different soil types, either on one farm or among several farms. Replication (to sample soil variation in each field) is also necessary.

Herbicide Trials

Herbicide and herbicide rate trials are subject to large variations among years and fields due to the fact that soil, weather, crop growth (and sometimes variety), and weed seed supply and growth all can affect the outcome. This makes it very difficult to prove conclusively that a particular herbicide, combination, or rate will be predictably better than another. The use of herbicide additives throws another variable into the mix and makes choosing a "best treatment" even more difficult. Trials in which different herbicides and rates need to be mixed and applied to strips are often very time-consuming.

Management Practices

It can be relatively easy to compare different plant populations or planting rates, although calibration of equipment—knowing how many seeds per acre or pounds per acre of seed are produced by a particular planter or drill setting—can be difficult. Changing the rates also needs to be done during the busy planting

season, but this can be made easier if calibration is done beforehand. As discussed in the section on fertilizer rate trials, two planting rates that differ only slightly may often produce similar yields, and finding a "best" planting rate is difficult. By careful replication of two or three different rates in a number of fields over several years, however, it might be possible (with little risk) to tell whether increased planting rates would increase yields.

"Interaction" and "Systems" Trials

Many crop production factors interact; that is, the response to one factor (plant population, for example) may depend on choices made related to other factors (hybrid, for example). While this is known in principle, it is difficult to design research to help apply this knowledge. The short life of many hybrids and varieties adds to this dilemma: once the research is done to determine the best population for a particular hybrid, that hybrid will likely no longer be available. An alternative is to try to identify hybrids that are "typical" for some characteristic and can thus represent a lot of other hybrids, both present and future. From a practical standpoint, this is virtually impossible, since it is not possible to know for certain that a hybrid is really typical, and the definition of a typical hybrid changes over time.

Interaction trials by definition also require more treatments than do one-factor trials. The simplest interaction trial has four treatments—two levels of one factor times two levels of another. And such a minimal number of treatments may not always tell researchers much. What would be learned, for example, if two plant populations were used with each of two hybrids? Farmers will learn that the hybrids react either the same or differently in relation to plant populations, but a "best" population will not be identified for either hybrid. It may well be more efficient to choose one hybrid as the better of the two, then use three or four different populations to try to see how to increase its yield. In this type of tradeoff, knowledge is limited to one hybrid, but the knowledge about it becomes much better.

Another example of the problem of measuring the effects of interactions is seen in "systems" research. In many such studies, several factors are changed simultaneously, typically ending up with only two treatments: the "conventional" system and the "new" system. While the simplicity of such trials is appealing, it is often impossible to separate out the effects of any of the changes the farmer made in going to the new system. In other words, it may be possible to compare the overall profitability of the two systems, but it is not possible to optimize—choose the best combination of inputs for—the system. Systems trials can be modified by including more treatments and leaving out one component of the new system for each treatment. This will tell how much, if any, each component contributes to the whole system, and will allow elimination of changes that are not necessary.

Risk Considerations

On-farm research trials should be selected and designed so that they carry little risk of loss. Many trials, such as those comparing hybrids or varieties, usually include only treatments that yield relatively well—and so represent little risk. It is probably best to avoid entries in such trials that are certain not to perform very well, unless there is special interest, for example, in knowing how modern varieties compare to old varieties.

Some types of trials involve considerable risk of yield loss, and the farmer should be aware of this. A good example is nitrogen rate trials that include the use of no nitrogen as one of the treatments. This treatment helps us determine if there is any response to nitrogen, but is probably not necessary to find the best rate; some nitrogen is usually needed for best yields. Thus researchers might use 60, 90, 120, 150, and 180 pounds of nitrogen per acre in a rate trial instead of using 0, 50, 100, 150, and 200 pounds. This will reduce the loss associated with rates that are too low. The closer spacing of rates will—as long as the range is wide enough to include the optimum rate—often do a better job of determining a best rate.

Another example in which untreated "checks" can cause yield losses would be herbicide trials, where the use of no herbicide might cause visually dramatic results but might be an impractical alternative. As these examples illustrate, it is probably better to restrict most on-farm research treatments to those necessary to identify the most *practical* treatment or rate, rather than to try to cover the whole range of possibilities, including treatments that may never be used on a field scale.

Getting Started with On-Farm Research

While there is a perception that on-farm research takes a lot of time and effort, the very large numbers of variety strip trials prove that farmers will take the necessary time to do such trials if the rewards are sufficient. Such rewards might be material—for example, additional seed often is given to variety strip trial cooperators—or intangible, such as cooperation in a group project that is expected to provide good information useful to all group members.

No matter what the perceptions about time and effort required to conduct on-farm research, it is essential that the work be clearly specified and assigned before the research begins. To do this, it is most useful to write down everything that will have to be done, when each task must be completed, and who will do each task. The important work gets done this way, and participants can see beforehand what they will need to do throughout the season to make the project work.

From a practical standpoint, it is best to undertake projects that do not interfere greatly with ongoing farming operations, particularly at planting and harvesting times. For example, it may be easier to apply nitrogen rates after planting than to delay planting in order to put on different rates. Work such as hybrid trials or planting rate trials that must be done at planting time can be planned for fields that are usually ready to plant first (or last) or by trying other ways to work around the main farm operations.

The following steps initiate on-farm research:

1. Decide what type of research is preferred. It is often better if this decision can be made by a group, perhaps a "club," operating with similar goals. It may also be prudent to ask advice from an experienced researcher at this stage. Such researchers may help to ask questions that focus the goal, and they may know of previous work that might prevent wasted effort.

2. Formulate *specific* objectives. For example, rather than "We want to compare different ways to plant soybeans," the objective might read, "We want to see how soybeans in 30-inch rows yield compared to those in 7-inch rows."

3. Formulate a research plan to answer questions including these:
   - how many locations and years the research will be conducted in
   - who will actually conduct the comparisons
   - what soil type restrictions (if any) there will be
   - what equipment, herbicide, or variety restrictions (if any) there will be
   - what data (for example, yield) will be taken
   - who will summarize the results

   Several meetings—field days, progress discussions, results discussions—should be scheduled as part of the plan. Make sure the plan is *practical* and that everyone understands his or her role and has the right equipment to do the work.

4. Pay attention to work underway, thus providing encouragement and accountability to individuals in the group. Field days help do this, along with coffeeshop meetings during the season. Set deadlines for assembling results, and telephone those who are late to keep everyone on schedule as much as possible.

5. Have an off-season progress meeting to summarize results. Plans can be modified for the next season, but remember that changing treatments or objectives partway through a project is often a fatal blow: the goals become fuzzy, and participants may feel that their work has been wasted. It is certainly inadvisable to stop short of the goal because the first year's results do not "prove" what people had hoped they would.

6. Have a final meeting to present and discuss results from the whole study. While members may choose their own interpretations of the results, such discussions are often educational and useful. New projects often come from discussions of completed ones.

A Word About Statistics

As explained earlier, statistical analysis involves assessing the variability that is always present, then making reasonable, mathematics-based judgments as to whether or not observed effects are due to chance or to treatments. When it is concluded that a reasonable chance exists that differences in production outcomes were in fact due to treatments, then it is said that treatment had a *significant effect.* This conclusion does not mean that it has been *proven* that the treatments caused differences, only that researchers are satisfied that they probably did so.

When researchers are unable to draw the conclusion that treatments differed, they say that the treatments were *not significantly different.* This does not mean that treatment had no effect. Rather, it says that the research trials were not able to detect such an effect. There are two possibilities here: either the treatments really did not have an effect, or they did have an effect, but the experiment was not adequate to detect it. Note the earlier indication that small effects are very difficult to prove. This is because unexplained variation ("background noise") will usually "drown out" small effects.

What can farmers and researchers do when they think treatments should have differed, but the research results fail to show that? If this occurs in one trial in one field in one year, then the obvious conclusion is that the research needs to be done again. Due to the nature of statistics, combining the results of a number of trials, even when each trial shows only

a small difference, may well show a significant treatment effect. The more replications (years, fields, strips within fields), the better—provided that each comparison is done carefully and that the conditions of each comparison are reasonably similar. Such combining of results provides much more confidence for making a final conclusion, whether or not it agrees with what research had previously predicted.

Doing statistical analysis is not always simple, and it may often be advisable to work with a researcher to get results analyzed. Remember that statistical analysis cannot improve on the research; no amount of analysis will rescue a trial where the research was done sloppily or was improperly designed. Many projects have been made useless by poor designs which do not allow proper analysis and thus do not allow conclusions that are supported by solid research.

Above all, keep an open mind: Research designed "to prove what we already know" is not research but a rather sterile exercise. At the same time, applied research almost always represents "work in progress." Researchers and farmers can benefit a great deal from the confidence such research in progress provides for a decision to adopt new production practices or continue more traditional ones. The increased knowledge that can be obtained from careful observation of a growing crop and its responses to evolving management practices benefits farming in general and society at large.

Author

Emerson D. Nafziger
Department of Crop Sciences

Selected Publications

Readers interested in reading more about a particular topic are referred to these publications, some of which were mentioned in the handbook. Many of the publications are available from a local Extension office. Many of them are also available for purchase from the College of Agricultural, Consumer and Environmental Sciences (ACES) ITCS, University of Illinois, 1917 South Wright Street, Champaign, Illinois 61820; (800)345-6087. Addresses for publications from other sources are also indicated.

Chapter 1. Agricultural Climatology

Field Crop Scouting Manual: A Guide to Identifying & Diagnosing Pest Problems, X880b (available from the College of Agricultural, Consumer and Environmental Sciences (ACES) ITCS, University of Illinois, 1917 South Wright Street, Champaign, Illinois 61820)

Pest Management & Crop Development Bulletin (distributed weekly throughout the growing season; subscriptions are available from the University of Illinois, ACES Newsletter Service, College of Agricultural, Consumer and Environmental Sciences (ACES), University of Illinois, 1917 South Wright Street, Champaign, Illinois 61820; (800)345-6087)

Chapter 2. Corn

S.R. Aldrich, W.O. Scott, and R.G. Hoeft. *Modern Corn Production, Third Edition.* A & L Publications, Champaign, Illinois

Corn and Sorghum Hybrid Test Results in Illinois (published annually and available each year after harvest from Department of Crop Sciences, N-305 Turner Hall, University of Illinois, 1102 South Goodwin Avenue, Urbana, Illinois 61801, or a local Extension office)

Corn Planting Date and Plant Population. *Jour. Prod. Agr.* 7:59–62, 1994

Soils of Illinois, B778 (available from ACES ITCS)

Chapter 3. Soybeans

Managing Deficient Soybean Stands, C1317 (available from ACES ITCS; offered free with $5 purchase only)

Performance of Commercial Soybeans in Illinois (available from Department of Crop Sciences, N-305 Turner Hall, University of Illinois, 1102 South Goodwin Avenue, Urbana, Illinois 61801, or a local Extension office)

Chapter 4. Small Grains

Wheat Performance in Illinois Trials (published annually and available from Department of Crop Sciences, N-305 Turner Hall, University of Illinois, 1102 South Goodwin Avenue, Urbana, Illinois 61801, or a local Extension office)

Chapter 5. Grain Sorghum

Corn and Sorghum Hybrid Test Results in Illinois (published annually and available each year after harvest from Department of Crop Sciences, N-305 Turner Hall, University of Illinois, 1102 South Goodwin Avenue, Urbana, Illinois 61801, or a local Extension office)

Chapter 6. Cover Crops and Cropping Systems

G.A. Bollero and D.G. Bullock. Cover Cropping Systems for the Central Corn Belt. *Jour. Prod. Agr.* 7:55–58, 1994

Chapter 7. Alternative Crops

Alternative Field Crops Manual (available from the Center for Alternative Plant and Animal Products, 352 Alderman Hall, 1970 Folwell Avenue, St. Paul, MN 55108)

Chapter 8. Hay, Pasture, and Silage

Hay That Pays: Hay Marketing, LW8 (available from ACES ITCS)

Illinois Seed Law publication, updated as there are changes in the law (available from Illinois Department of Agriculture, Bureau of Agricultural Products Inspection, P.O. Box 19281, State Fair Grounds, Springfield, Illinois 62794)

The Land Under Cover: Hay and Pasture Management, LW7 (available from ACES ITCS)

1999 Illinois Agricultural Pest Management Handbook, IAPM-99 (available from ACES ITCS)

Returning to Grass Roots: Hay and Pasture Establishment, LW6 (available from ACES ITCS)

Chapter 9. Seed

Illinois Seed Law publication, updated as there are changes in the law (available from Illinois Department of Agriculture, Bureau of Agricultural Products Inspection, P.O. Box 19281, State Fair Grounds, Springfield, Illinois 62794)

Chapter 10. Water Quality

50 Ways Farmers Can Protect Their Groundwater, NCR-522 (available from ACES ITCS)

Protecting Your Water Supply from Ag Chemical Backflow, E2349 (available from ACES ITCS)

Water Quality and the Hydrologic Cycle: How Water Movement Affects Quality, LW13 (available from ACES ITCS)

Chapter 11. Soil Testing and Fertility

Illinois Voluntary Limestone Program Producer Information (an annual publication available from Illinois Department of Agriculture, Bureau of Agricultural Products Inspection, P.O. Box 19281, State Fair Grounds, Springfield, Illinois 62794)

Color Chart for Estimating Organic Matter in Mineral Soils in Illinois, AG-1941 (available from ACES ITCS)

Soil Plan (available from IlliNet Software, 548 Bevier Hall, Urbana, Illinois 61801)

Compendium of Research Reports on the Use of Nontraditional Materials for Crop Production, NCR-103 (available from Publications Distribution, Printing and Publishing Building, Iowa State University, Ames, Iowa 50011, or your local Extension office)

Chapter 12. Soil Management and Tillage Systems

The Residue Dimension—Managing Residue to Control Erosion, LW9 (available from ACES ITCS)

J. Siemens, K. Hamburg, and T. Tyrrell. A Farm Machinery Selection and Management Program. *Jour. Prod. Agr.* 3: 212–219, April–June 1990

Chapter 13. No Tillage

Conservation Tillage Systems and Management: Crop Residue Management with No-Till, Ridge-Till, Mulch-Till, MWPS-45 (available from MidWest Plan Service, Department of Agricultural Engineering, University of Illinois, 332 AESB, 1304 West Pennsylvania Avenue, Urbana, Illinois 61801)

Weed Control Systems for Lo-Till and No-Till, C1306 (available from ACES ITCS)

Chapter 14. Water Management

Illinois Drainage Guide, C1226 (available from ACES ITCS)

Chapter 16. 1999 Weed Control for Small Grains, Pastures, and Forages

1999 Illinois Agricultural Pest Management Handbook, IAPM-99 (available from ACES ITCS)

Herbicide-Resistant Weeds, NCR-468 (available from ACES ITCS)

Illinois Drainage Guide, C1226 (available from ACES ITCS)

Quackgrass Control in Field Crops, NCR-219 (available from ACES ITCS)

Weed Control Systems for Lo-Till and No-Till, C1306 (available from ACES ITCS)

Weeds of the North Central States, B772 (available from ACES ITCS)

Chapter 17. Management of Field Crop Insect Pests

1999 Illinois Agricultural Pest Management Handbook, IAPM-99 (available from ACES ITCS)

Bt-Corn and European Corn Borer: Long-Term Success Through Resistance Management (available from ACES ITCS)

Conservation Tillage Systems and Management: Crop Residue Management with No-Till, Ridge-Till, Mulch-Till, MWPS-45 (available from MidWest Plan Service, Department of Agricultural Engineering, University of Illinois, 332 AESB, 1304 West Pennsylvania Avenue, Urbana, Illinois 61801)

Corn Insect Pests: A Diagnostic Guide (available from ACES ITCS)

Field Crop Scouting Manual: A Guide to Identifying & Diagnosing Pest Problems, X880b (available from ACES ITCS)

Pest Management & Crop Development Bulletin (distributed weekly throughout the growing season; subscriptions are available from the University of Illinois, ACES Newsletter Service, College of Agricultural, Consumer and Environmental Sciences (ACES), University of Illinois, 1917 South Wright Street, Champaign, Illinois 61820; (800)345-6087)

Chapter 18. Disease Management for Field Crops

1999 Illinois Agricultural Pest Management Handbook, IAPM-99 (available from ACES ITCS)

Various reports on plant diseases (available from Department of Crop Sciences, N-305 Turner Hall, University of Illinois, 1102 South Goodwin Avenue, Urbana, Illinois 61801)

Useful Facts and Figures

To convert column 1 into column 2, multiply by	Column 1	Column 2	To convert column 2 into column 1, multiply by
	Length		
0.621	kilometer, km	mile, mi	1.609
1.094	meter, m	yard, yd	0.914
0.394	centimeter, cm	inch, in.	2.54
16.5	rod, rd	feet, ft	0.061
	Area		
0.386	kilometer^2, km^2	mile^2, mi^2	2.59
247.1	kilometer^2, km^2	acre, acre	0.004
2.471	hectare, ha	acre, acre	0.405
	Volume		
0.028	liter	bushel, but	35.24
1.057	liter	quart (liquid), qt	0.946
0.333	teaspoon, tsp	tablespoon, tbsp	3
0.5	fluid ounce	tablespoon, tbsp	2
0.125	fluid ounce	cup	8
29.57	fluid ounce	milliliter, ml	0.034
2	pint	cup	0.5
16	pint	fluid ounce	0.063
	Mass		
1.102	ton (metric)	ton (English)	0.907
2.205	kilogram, kg	pound, lb	0.454
0.035	gram, g	ounce (avdp.), oz	28.35
	Yield		
0.446	ton (metric)/hectare	ton (English)/acre	2.24
0.891	kg/ha	lb/acre	1.12
0.891	quintal/hectare	hundredweight/acre	1.12
0.016	kg/ha–corn, sorghum, rye	bu/acre	62.723
0.015	kg/ha–soybean, wheat	bu/acre	67.249
	Temperature		
(9/5·C) + 32	Celsius	Fahrenheit	5/9(F – 32)

Plant Nutrition Conversion

P (phosphorus) x 2.29 = P_2O_5 | P_2O_5 x .44 = P

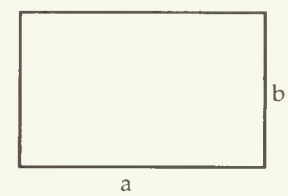
K (potassium) x 1.2 = K_2O | K_2O x .83 = K

ppm x 2 = lb/A (assumes that an acre plow depth of 6 ⅔ inches weighs 2 million pounds)

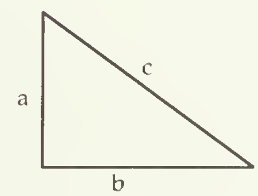
Useful Equations

$$\text{Speed (mph)} = \frac{\text{distance (ft)} \times 60}{\text{time (seconds)} \times 88}$$

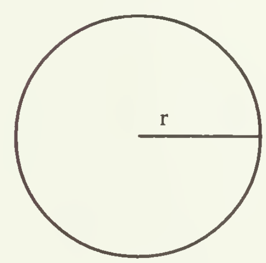
1 mph = 88'/min



Area = a x b



Area = ½ (a x b)



Area = πr^2

$\pi = 3.1416$

$$\text{lb/100 ft}^2 = \frac{\text{lb/acre}}{435.6}$$

$$\text{Example: 10 tons/acre} = \frac{20{,}000 \text{ lb}}{435.6} = 46 \text{ lb/100 ft}^2$$

$$\text{oz/100 ft}^2 = \frac{\text{lb/acre}}{435.6} \times 16$$

$$\text{Example: 100 lb/acre} = \frac{100}{435.6} \times 16 = 4 \text{ oz/100 ft}^2$$

$$\text{tsp/100 ft}^2 = \frac{\text{gal/acre}}{435.6} \times 192$$

$$\text{Example: 1 gal/acre} = \frac{1}{435.6} \times 192 = .44 \text{ tsp/100 ft}^2$$

Water weight = 8.345 lb/gal

Acre-inch water = 27,150 gal

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- increased focus on the problem with western corn rootworms in corn planted after soybeans
- improved information about managing European corn borers with *Bt*-corn
- effects of El Niño and La Niña on Illinois corn and soybean yields
- update on phosphorus and the environment: its impact on water quality
- the pros and cons of strip tillage for your corn